WATER QUALITY MONITORING

AT BLUE MARSH RESERVOIR

DURING 2002

Prepared for

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Philadelphia District
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Contract No. DACW61-00-D-0009
Delivery Order No. 0033

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January 2003

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

Table No. **Page**

LIST OF TABLES (Continued)

Table No. **Page**

LIST OF FIGURES

Figure No. **Page**

LIST OF FIGURES (Continued)

Figure No. **Page**

LIST OF FIGURES (Continued)

Figure No. **Page**

1.0 INTRODUCTION

1.1 PURPOSE OF THE MONITORING PROGRAM

The U.S. Army Corps of Engineers (USACE) manages Blue Marsh Reservoir located in east-central Pennsylvania on the Tulpehocken Creek, which is within the Delaware River Basin. Foremost, Blue Marsh Reservoir provides flood control and a dependable water supply to downstream communities west of Reading, PA. Additionally, the reservoir provides important habitat for fish, waterfowl, and other wildlife, and recreational opportunities through fishing, boating, and swimming. Due to the broad range of uses and demands that Blue Marsh Reservoir serves, the USACE monitors water quality, and other aspects related to ecological health, primarily to ensure public health safety. Results from water quality monitoring are compared to state water quality standards and used to diagnose other problems that commonly affect reservoir health such as nutrient enrichment and toxic loadings. This report summarizes the results of water quality monitoring at Blue Marsh Reservoir from May to October 2002. This report also discusses the relevance of the water quality measures to the ecology of the reservoir and makes recommendations toward future water quality monitoring.

1.2 DESCRIPTION OF BLUE MARSH RESERVOIR

Blue Marsh Reservoir was designed to provide flood control, a water supply, and enhanced water quality to downstream communities along Tulpehocken Creek. Located about six miles northwest of Reading, Pennsylvania near Route 183, the reservoir dams a drainage area of 175 square miles. The dam, completed in 1979, can impound up to 42.3 billion gallons of water. The primary surface water inputs into Blue Marsh Reservoir other than Tulpehocken Creek include Wolf, Northkill, and Little Northkill Creek from the northwest; Spring Creek from the west; and Licking Creek from the northeast. The reservoir is approximately 6 miles long and is 52 feet deep immediately above the dam near Lower Heidelberg. The average annual discharge from the dam into Tulpehocken Creek is approximately 181 MGD (USGS 1993).

The most significant known point source of nutrient contamination affecting the ecological health of Blue Marsh Reservoir is the Bernville Wastewater Treatment Plant. This plant is located within the headwaters of the reservoir upstream on Northkill Creek. A combined sewage and storm water facility, the plant discharges approximately 0.14 million gallons per day (MGD) of secondary treatment water to the reservoir.

1.3 ELEMENTS OF THE STUDY

The USACE, Philadelphia District, has been monitoring the water quality of Blue Marsh Reservoir since 1979. Over this time, the yearly monitoring designs have evolved to address new concerns such as health of public drinking water and contamination of reservoir bottom sediments. The 2002 monitoring program follows that in most recent years and includes the following major elements:

- Monthly water quality monitoring of reservoir and upstream sources - to evaluate compliance with Pennsylvania state water quality standards;

- Semi-weekly coliform bacteria monitoring - to ensure public health and safety at the Blue Marsh Reservoir swimming beach area;

- Sediment priority pollutant monitoring of PCB's, pesticides, and volatile organic compounds to evaluate sediment toxicity relative to USACE identified screening concentrations;

- Arsenic monitoring to determine if arsenic mobilizes into the water column during periods of bottom water anoxia. Testing of arsenic concentrations in the sediment and bottom water is conducted in Blue Marsh Reservoir to monitor potential environmental effects from a hazardous waste site located 18 miles upstream in Tulpehocken Creek. The source of arsenic is resumed to have come from the Whitmoyer Plant that in the 1960s manufactured a veterinary drug of arsenic origin. A by-product of drug production process was stored in holding ponds on the property, and eventually contaminated groundwater. The Rohm and Haas Company purchased the Whitmoyer plant in 1964 and recovered much of the arsenic contamination. However, concerns remain over the historic loadings and their potential effects on reservoir sediments. Sediments high in arsenic concentrations could be a source of toxic trivalent arsenic III, particularly under reducing conditions in anoxic bottom waters. Iron concentrations have been measured in previous monitoring years because iron and arsenic have similar redox sensitivities. Thus, measurements of iron fluxes should aid in the interpretation of the arsenic monitoring results; and

- Drinking water monitoring - to ensure public health and safety by comparing water from a public drinking water source to standards determined by the Safe Drinking Water Act (SDWA).

2.0 METHODS

2.1 PHYSICAL STRATIFICATION MONITORING

Physical stratification monitoring of the water column was conducted monthly at Blue Marsh Reservoir from May to October 2002 (Table 2-1). Stratification parameters included temperature, dissolved oxygen (DO), pH, and conductivity. Monitoring was conducted at twelve fixed stations located throughout the reservoir watershed (Fig. 2-1). Six stations were located within the reservoir body (BM-2, BM-6, BM-7, BM-8, BM-9, and BM-10) for which water quality was measured from surface to bottom at 5-ft depth intervals. The other six stations (BM-1, BM-3, BM-4, BM-5, BM-11, and BM-12) were monitored for surface water quality only. All water quality parameters were measured with a calibrated Hydrolab water quality meter.

For this report, all of the stratification monitoring results were summarized and compared to water quality standards enacted by the Pennsylvania Department of Environmental Protection (PADEP –Chapter 93 Water Quality Standards). The water quality standard for DO is a minimum concentration of 5-mg/L and that for pH is a range of acceptability between 6 and 9.

2.2 WATER COLUMN CHEMISTRY MONITORING

Water column chemistry monitoring was conducted five times (approximately once a month) at Blue Marsh Reservoir during 2002 from May to October (Table 2-1). Due to scheduling problems, the late September sampling was conducted in the first week of October. Water samples were collected at 12 fixed stations in the reservoir watershed (Fig. 2-1). Surface water samples were collected at stations downstream of the reservoir (BM-1), and upstream of the reservoir on Spring Creek (BM-3), Licking Creek (BM-4), Tulpehocken Creek (BM-5) and Northkill Creek (BM-11 and BM-12). Surface, middle, and bottom water samples were collected at the 6 stations within the reservoir (BM-2, BM-6, BM-7, BM-8, BM-9, and BM-10). Surface water samples were collected by opening sample containers approximately one foot below the surface of the water. Middle and bottom water samples were collected with a Van Dorn design horizontal water bottle or well-monitoring pump using polyethylene tubing.

Water samples from all depths were analyzed for ammonia, nitrite, nitrate, total Kjeldahl nitrogen (TKN), total phosphorus, total dissolved phosphorus, dissolved phosphate, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), alkalinity, and chlorophyll *a*. Additionally, surface water samples collected at stations BM-2, BM-6, BM-7, BM-8, BM-9 and BM-10 were analyzed for purgeable aromatic compounds (benzene, toluene, ethylbenzene, and xylenes; i.e., BTEX). Table 2-2 summarizes the laboratory methods detection limits, state water quality standards, and

Table 2-1. Water quality monitoring schedule of Blue Marsh Reservoir during 2002. Monitoring was conducted at 12 fixed stations located throughout the reservoir watershed.

Date of Sample Collection	Physical Stratification Monitoring	Water Column Chemistry Monitoring (all stations)	Trophic State Assessment (all stations except BM-1)	Coliform Bacteria Monitoring (all stations)	Sediment Priority Pollutant Monitoring (stations BM-2 and -6)	Arsenic Monitoring (stations BM-2 and -6)	Drinking* Water Monitoring
13 March							Sets A and B
20 May	X	X	X	X			
18 June	X	X	X	X			Set A
22 July	X	X	X	X	X	X	
19 August	X	X	X	X			Sets A and B
1 October	X	X	X	X		X	
10 October							Set A

*Set A – comprised analyses for nitrate, nitrite, and coliform bacteria contaminants
Set B – comprised analyses for primary and secondary contaminants

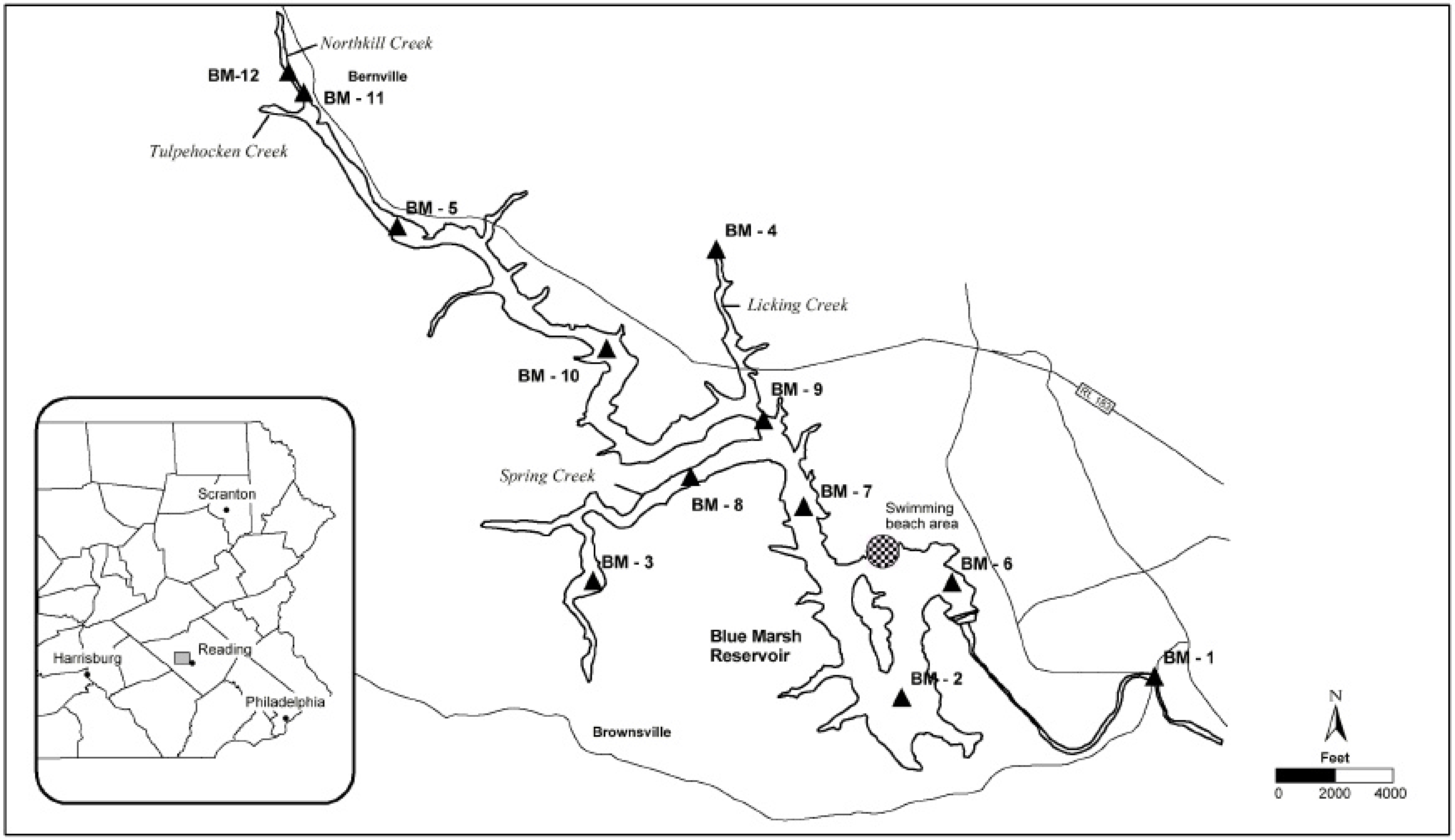

Figure 2-1. Blue Marsh Reservoir and the location of the 12 fixed stations monitored for water quality during 2002

sample holding times for each water quality parameter monitored. All water samples collected in 2002 were analyzed within their respective maximum allowable hold times.

Table 2-2. Water quality test methods, detection limits, state water quality standards, and sample holding times for water quality parameters monitored at Blue Marsh Reservoir in 2002

Parameter	EPA Method	Detection Limit	PADEP Water Quality Standards	Allowable Hold Times (Days)	Maximum Hold Time Achieved (Days)
Alkalinity	310.1	1-mg/L	minimum 20-mg/L $CaCO_3$	14	13
Biochemical Oxygen Demand (BOD)	SM5210B	2-mg/L	None	2	2
Total Phosphorus	365.2	0.01-mg/L	None	28	1
Total Dissolved Phosphorus	365.2	0.01-mg/L	None	28	9
Dissolved Phosphate	365.2	0.01-mg/L	None	28	9
*Chlorophyll *a*			None		4
Total Kjeldahl Nitrogen	351.3	0.10-mg/L	None	28	14
Ammonia	350.3	0.05-mg/L	Temperature and pH dependent	28	10
Nitrate	353.2	0.1-mg/L	Maximum 10-mg/L (nitrate + nitrite)	2	2
Nitrite	354.1	0.01-mg/L		2	2
Total Dissolved Solids @ 180 ºC	160.1	10-mg/L	Maximum 500-mg/L	7	6
Total Suspended Solids	160.2	1-mg/L	None	7	6
Benzene	8260B	1-µg/L	128-µg/L	14	9
Ethylbenzene	8260B	1-µg/L	580-µg/L	14	9
Toluene	8260B	1-µg/L	330-µg/L	14	9
Xylenes	8260B	1-µg/L	211-µg/L	14	9

* Chlorophyll *a* samples were calculated by averaging 10 readings per minute using a YSI 6600 with a chlorophyll sensor.

2.3 TROPHIC STATE DETERMINATION

The trophic state of Blue Marsh Reservoir was determined by methods outlined by Carlson (1977). In general, this method calculated trophic state indices (TSIs) independently for measures of total phosphorus, chlorophyll *a*, and secchi disk depth. Surface water measures of total phosphorus and chlorophyll *a* from chemistry monitoring were averaged in the calculation of monthly TSIs (Table 2-1). Secchi disk depth was measured at all stations except BM-1, BM-5, BM-11, and BM-12 and similarly averaged for the TSI calculation. Trophic state determinations were made using criteria defined by Carlson and EPA (1983).

2.4 RESERVOIR COLIFORM BACTERIA MONITORING

Monitoring for coliform bacteria contaminants was conducted monthly at Blue Marsh Reservoir. Water samples were analyzed for total coliform, fecal coliform, and at stations BM-11 and BM-12 fecal streptococcus bacteria. Surface water samples were tested at all stations. Table 2-3 presents the test methods, detection limits, PADEP water quality standards, and sample holding times for the bacteria parameters monitored at Blue Marsh Reservoir in 2002. The bacteria analytical method was based on a membrane filtration technique. All of the samples were analyzed within their respective maximum allowable hold times. At the end of the monitoring period, stream flow data (CFS) collected from a USGS gauging station in the region (Bernville) and precipitation data collected at the Blue Marsh Dam were used to correlate rainfall patterns with measured bacteria levels.

Table 2-3. Water quality test methods, detection limits, PADEP water quality standards, and sample holding times for bacteria parameters monitored at Blue Marsh Reservoir in 2002

Parameter	**Total Coliform**	**Fecal Coliform**	**Fecal Streptococcus**
Test method	SM 9222B	SM9222D	SM9230C
Detection limit	10 clns/ 100-mls	10 clns/100-mls	10 clns/ 100-mls
PADEP water quality standard	-	Geometric mean < 200 clns/100-mls	-
PA Department of Health	-	Geometric mean < 200 clns/100-mls. No sample > 1000 clns/ 100-mls	-
Maximum allowable holding time	30 hours	30 hours	30 hours
Achieved holding time	< 30 hours	< 30 hours	< 30 hours

Coliform bacteria counts were compared to the PADEP water quality standards for bacteria. The standard is defined as a maximum geometric mean of 200 colonies/100-ml based on 5 samples collected on different days. Given our logistical limitations (all monthly sampling conducted in a single day), we calculated the geometric mean based on all of the surface reservoir samples collected on the day of monitoring. Although our sampling design does not fully meet PADEP guidelines, we feel that this interpretation of the coliform data meets the intent of the PADEP water quality standard for evaluating Blue Marsh Reservoir bacteria levels.

2.5 STREAMFLOW AND PRECIPITATION DATA

Stream flow and precipitation data spanning the months monitored from May to September were compiled from USACE records (Figs. 2-2 through 2-7). Stream flow data were collected at the USGS gauging station located in Bernville and reflect rainfall patterns throughout the watershed of Blue Marsh Reservoir. Precipitation data were collected by Blue Marsh Reservoir personnel and reflect more localized rainfall patterns. Overall, stream flow and precipitation records were largely in agreement throughout the monitoring period. In May, significant rain events occurred with precipitation measures exceeding 0.5 inches and stream flow reaching 270-cfs (Fig. 2-2). Monitoring for general water quality parameters was conducted two days after the highest flow for the month of May. In June, several small rain events occurred and one larger one that exceeded 1.5 inches. Monthly monitoring for 18 June was conducted at a stream flow of 78-cfs during an insignificant rainfall of 0.17 inches (Fig. 2-3). Throughout July, stream flow gradually decreased from 77-cfs to 33-cfs (Fig. 2-4) and the sampling for the month was taken during the lowest flows recorded. Samples for general water quality parameters were collected on 19 August right before a couple of days of rainfall. The rainfall was not significant enough to increase the flow. Stream flow remained consistent between 32-cfs and 42-cfs (Fig. 2-5). A rain event of one inch on the 26 and 27 of September caused stream flow to increase to 118-cfs (Fig. 2-6). Monthly monitoring in 1 October occurred after the precipitation event in September (Fig. 2-7). The stream flow level was back to the level of 40-cfs.

2.6 SWIMMING BEACH MONITORING

Additional coliform bacteria monitoring was conducted twice weekly near the public swimming beach at the Dry Brooks day use area (Table 2-4). Three stations were monitored in the swimming beach area for total coliform, fecal coliform, fecal streptococcus, and Escherichia coli (SB-1, SB-2, and SB-3; Fig. 2-8). Additionally, weekly monitoring for total coliform and fecal coliform was conducted at a station BM-11 and BM-12 on Northkill Creek downstream and upstream of the Bernville wastewater treatment facility (Fig. 2-1). The coliform bacteria samples were collected and analyzed by the same methods used for monthly coliform bacteria sampling. The bacteria monitoring for Blue Marsh Swimming Beach followed a 4-step program of conditional monitoring. Each step or "condition" of monitoring responded to incremental increases of coliform contamination, and therefore increased risk to public health at the swimming beach area.

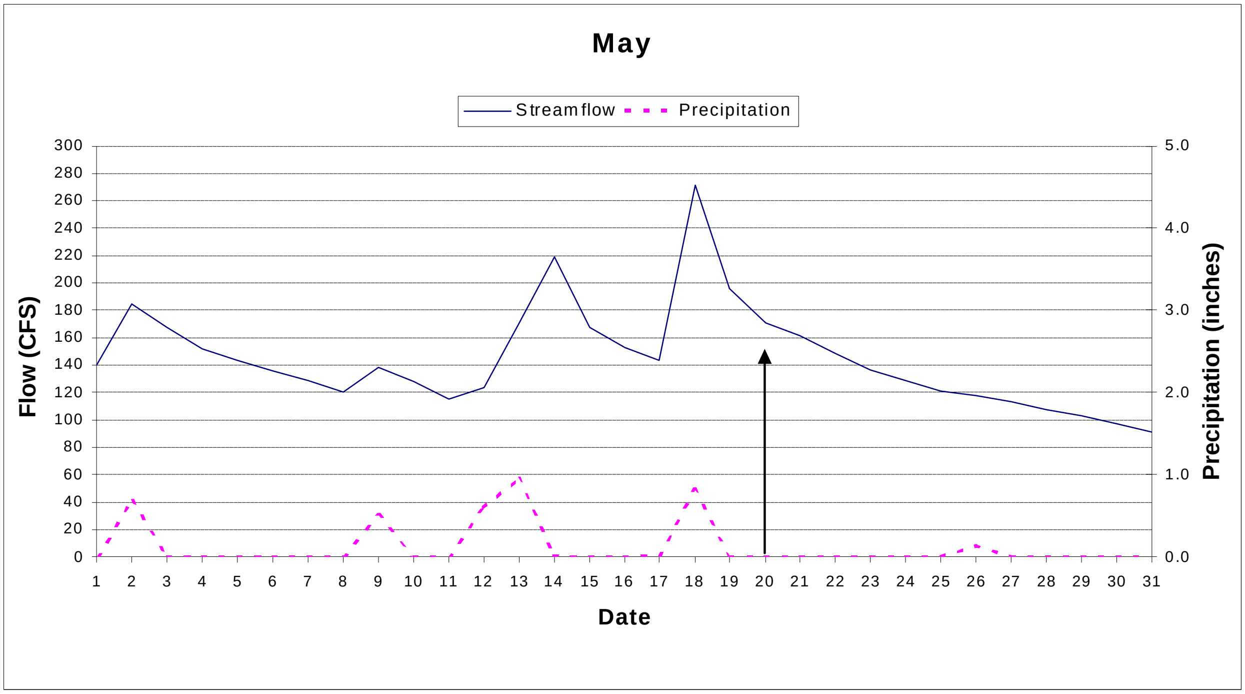

Figure 2-2. Streamflow and precipitation in the vicinity of Blue Marsh Reservoir during May 2002

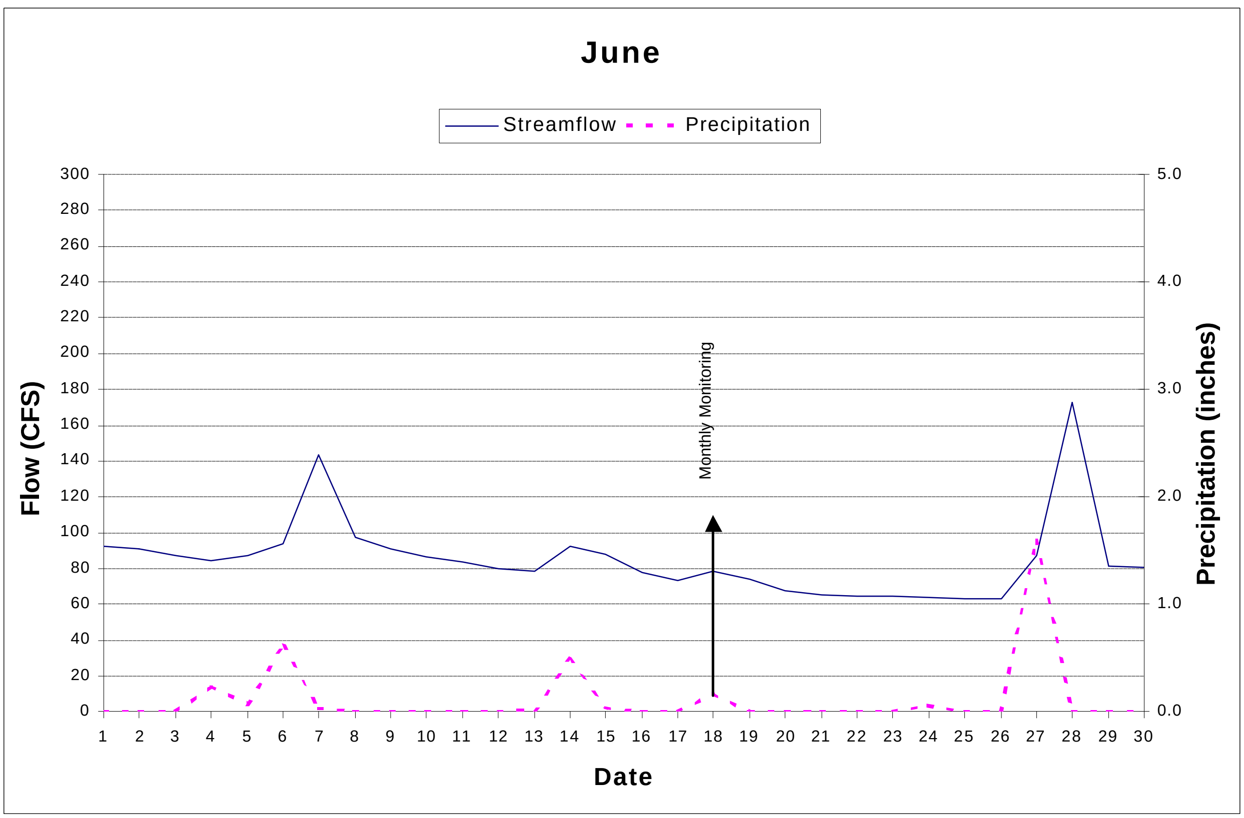

Figure 2-3. Streamflow and precipitation in the vicinity of Blue Marsh Reservoir during June 2002

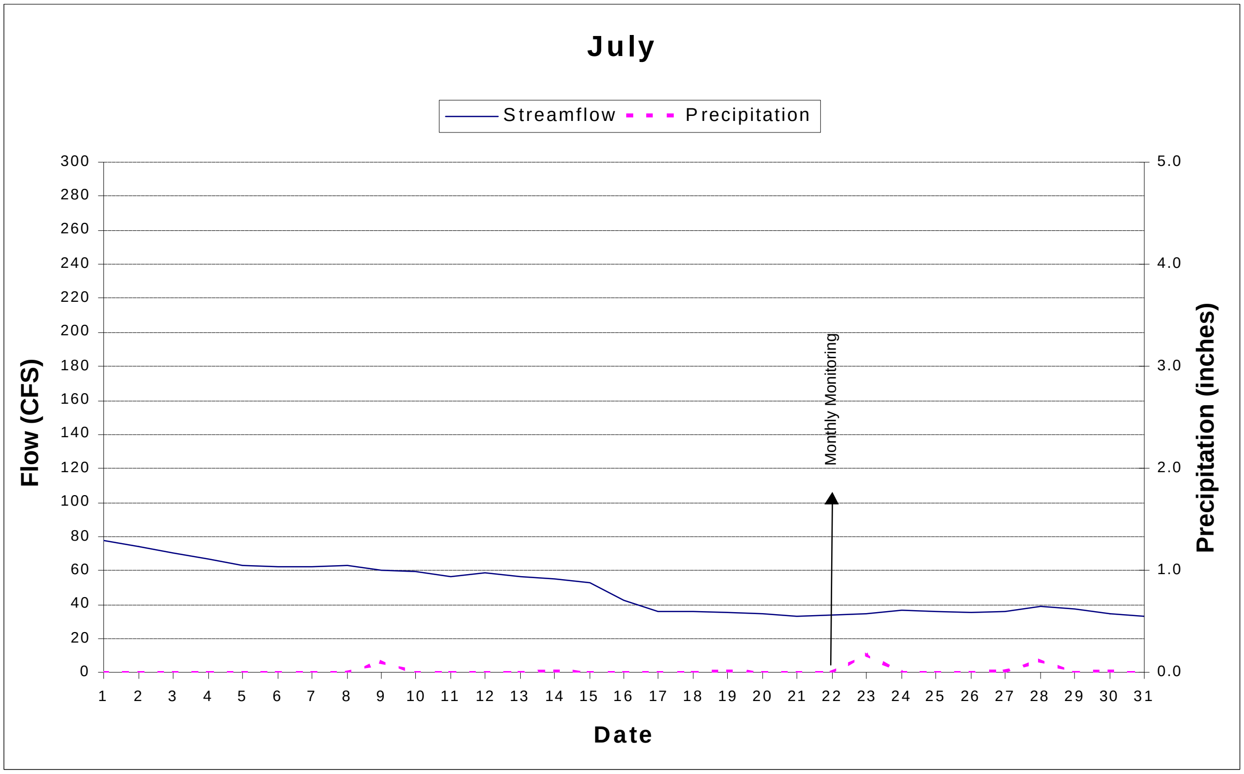

Figure 2-4. Streamflow and precipitation in the vicinity of Blue Marsh Reservoir during July 2002

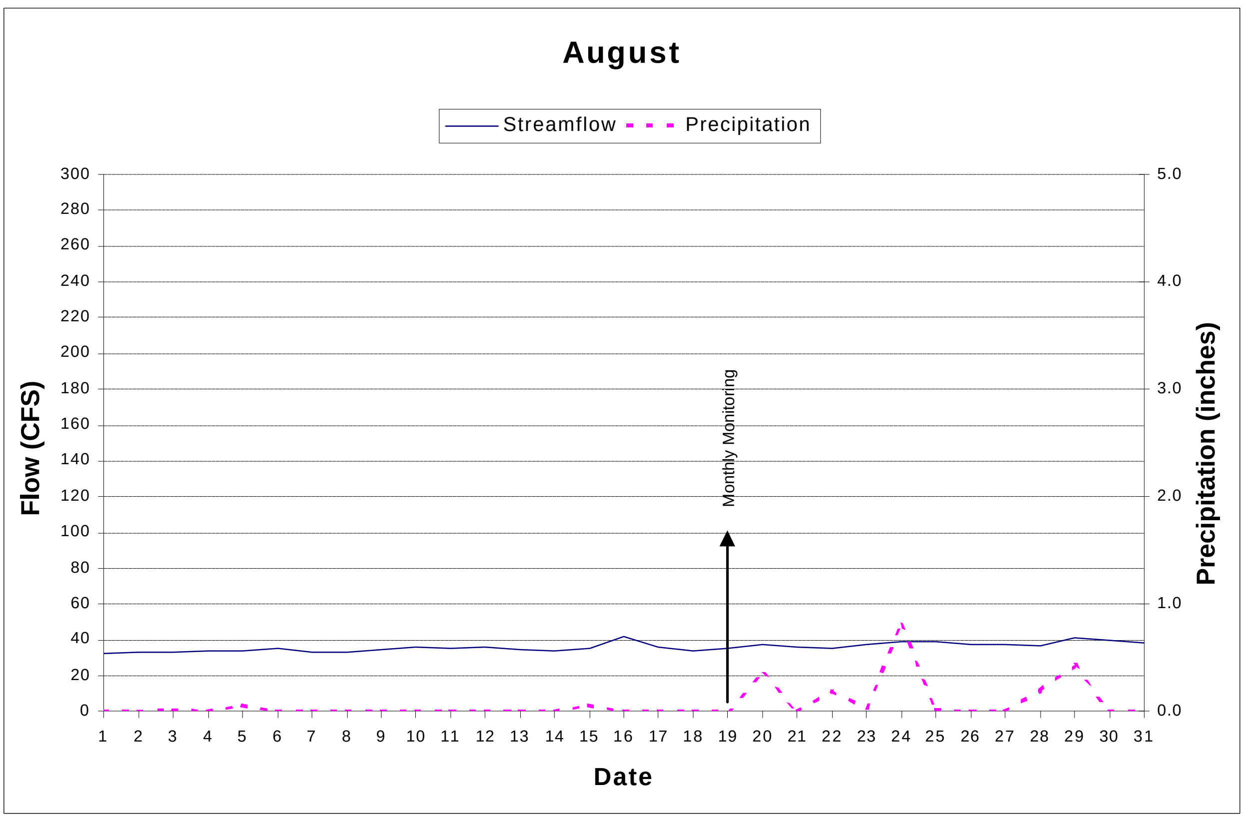

Figure 2-5. Streamflow and precipitation in the vicinity of Blue Marsh Reservoir during August 2002

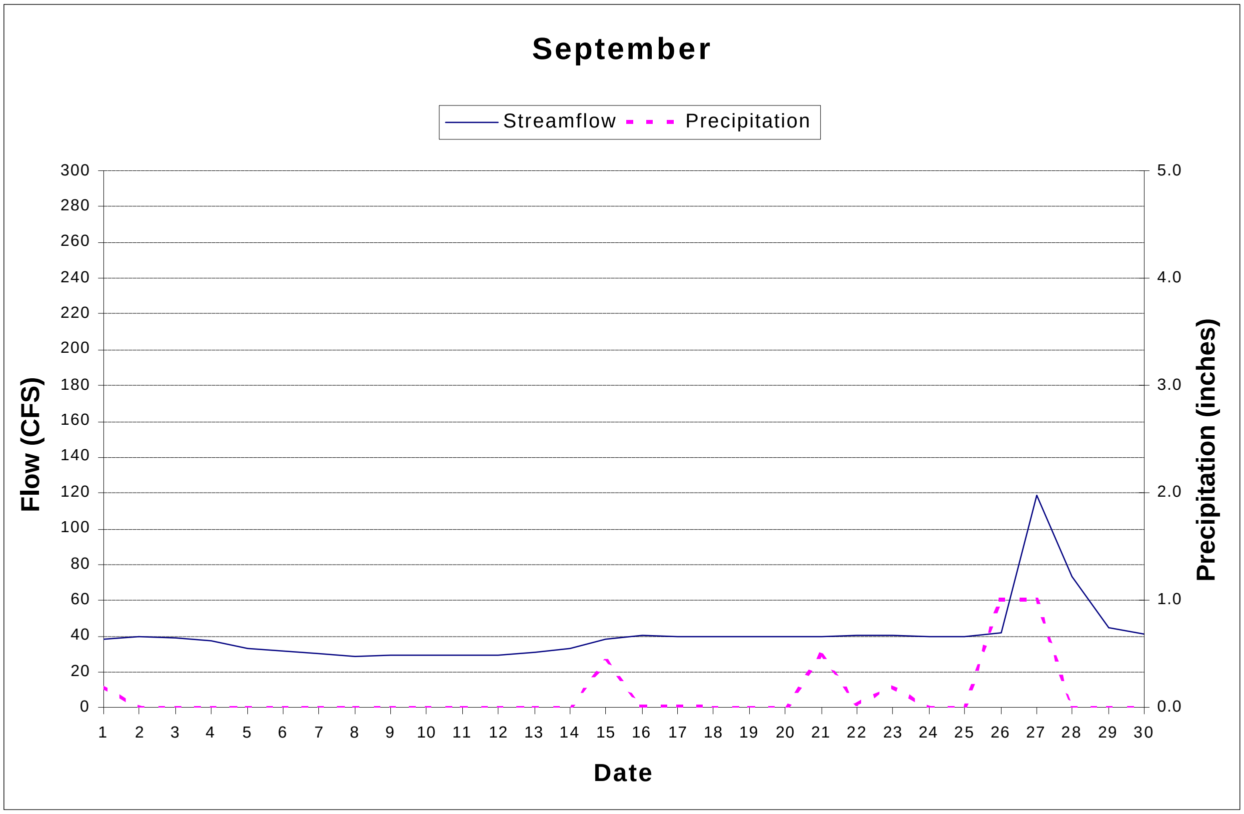

Figure 2-6. Streamflow and precipitation in the vicinity of Blue Marsh Reservoir during September 2002

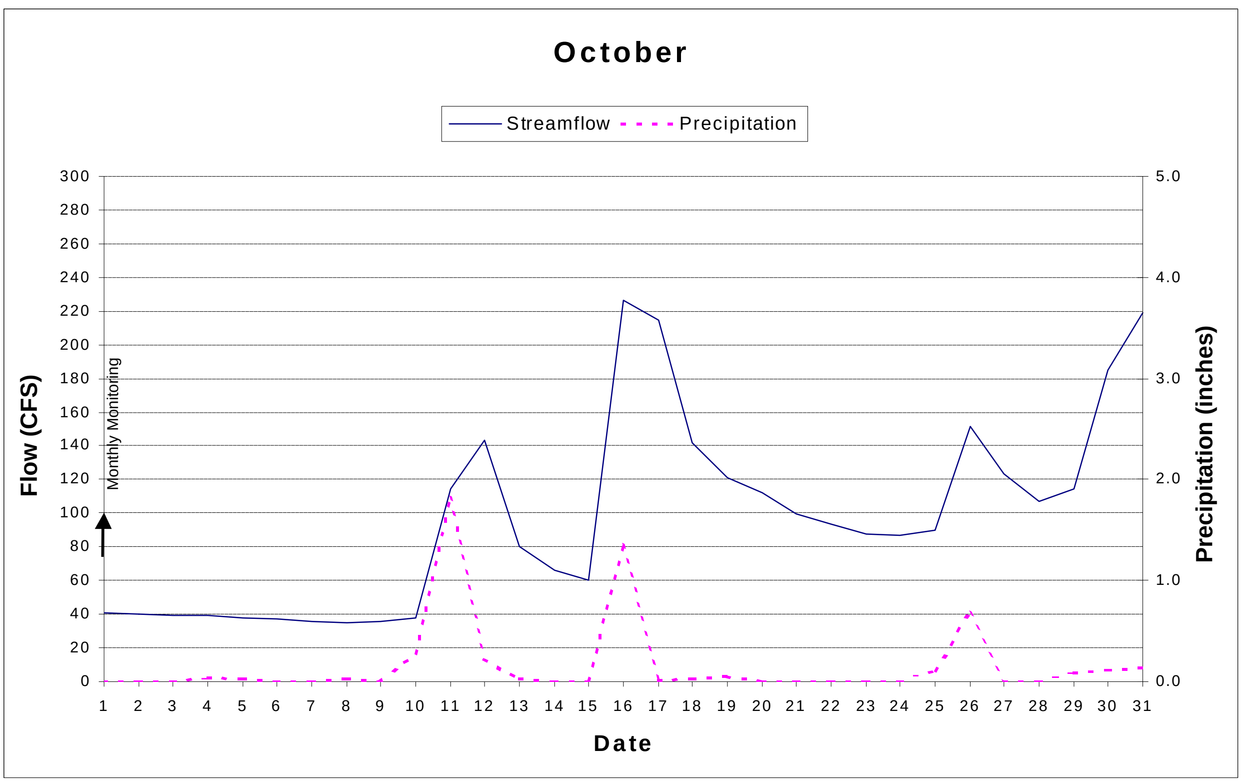

Figure 2-7. Streamflow and precipitation in the vicinity of Blue Marsh Reservoir during October 2002

Table 2-4. Sampling dates for coliform bacteria monitoring at the Blue Marsh Reservoir swimming beach during 2002

Week 1	9 May	**Week 11**	15 and 18 July
Week 2	13 and 16 May	**Week 12**	22 and 25 July
Week 3	20 and 23 May	**Week 13**	29 July and 1 August
Week 4	28 and 30 May	**Week 14**	5 and 8 August
Week 5	3 and 6 June	**Week 15**	12,13,14,15,16 and 17 August
Week 6	10 and 13 June	**Week 16**	18,19,20,21,22,23 and 24 August
Week 7	17 and 20 June	**Week 17**	25,26,27,28,29,30 and 31 August
Week 8	24 and 27 June	**Week 18**	2 and 5 September
Week 9	1 and 3 July	**Week 19**	9 and 12 September
Week 10	8 and 11 July	**Week 20**	16 September

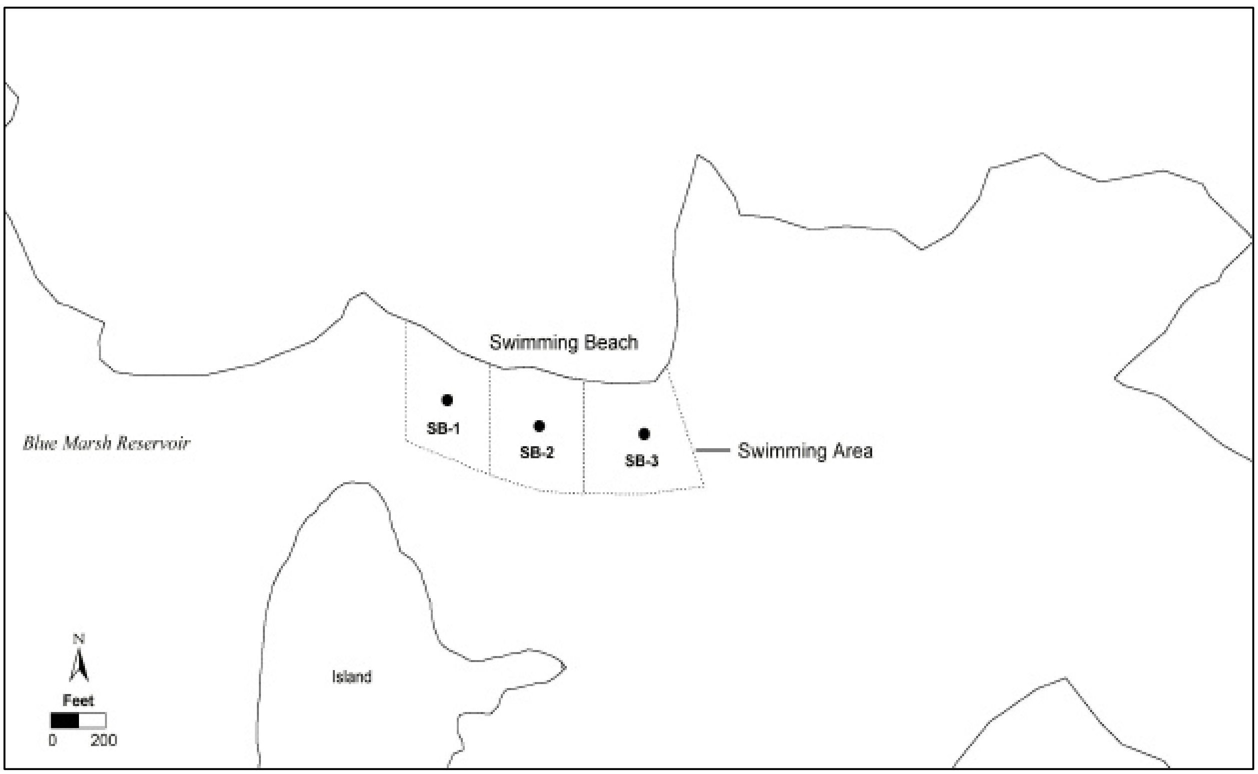

Figure 2-8. Swimming beach bacteriological monitoring stations at Blue Marsh Reservoir in 2002

2.7 SEDIMENT PRIORITY POLLUTANT MONITORING

Sediment from Blue Marsh Reservoir was monitored for priority pollutant contaminants, Group 1 - PCB's, pesticides, and volatile organic compounds. Sediment was collected 22 July at station BM-2 and BM-6 with a petite ponar grab-sampler. Sediment from the grab-sampler was emptied into a stainless steel mixing bowl and homogenized with a stainless steel spoon. Sediments were contained in appropriately labeled sample jars and stored on ice until shipment to the analytical laboratory. All field equipment used during the handling of reservoir sediments was decontaminated prior to sampling.

Decontamination procedures were as follows: gross rinse, detergent wash, first deionized water rinse, 10% nitric acid rinse, second deionized water rinse, hexane rinse, and third deionized water rinse. Table 2-5 summarizes the parameters monitored, method detection limits, sample hold times, and the laboratory methods used in the analyses. Mercury was not analyzed during sediment sampling because of sample processing error. All of the sediment priority pollutant parameters were analyzed within their respective maximum allowable hold times.

Sediment contaminant concentrations were reported based on dry weight and are calculated as follows:

$$\text{Dry weight concentration (mg/kg)} = \frac{\text{Wet weight concentration (mg/kg)} \times 100}{\text{\% solids of sample}}$$

Sample-specific detection limits were calculated because of the conversion from wet weight to dry weight. Therefore each sample has a different detection limit (Table 2-5).

2.8 ARSENIC AND IRON MONITORING

Arsenic and iron monitoring of sediment and water was also conducted at stations BM-2 and BM-6 (Fig. 2-1). Sediment and reservoir bottom water samples were collected on 22 July and 1 October. Sediment samples were collected with a decontaminated petite ponar grab (as in Section 2.6). Sediment samples were analyzed for total arsenic and iron. Bottom water samples were collected with a Van Dorn design horizontal water bottle. Water samples were analyzed for total and dissolved (passed through a 10-µm glass filter) arsenic and iron. Table 2-6 summarizes the detection limits, analytical methods, and sample hold times used in the arsenic and iron testing of water and sediments. All of the arsenic and iron samples were analyzed within the maximum allowable hold times for each parameter.

Table 2-5. Sediment priority pollutants, Group 1 –volatile organic compounds, PCB's, and pesticides monitored at Blue Marsh Reservoir during 2002.

Parameter	Units	Method Detection Limit BM-6 and BM-2
PCBs - Method 8082		
Aroclor-1016	ppb	100
Aroclor-1221	ppb	100
Aroclor-1232	ppb	100
Aroclor-1242	ppb	100
Aroclor-1248	ppb	100
Aroclor-1254	ppb	100
Aroclor-1260	ppb	100
Pesticides - Method 8081A		
4,4'-DDD	ppb	4
4,4'-DDE	ppb	4
4,4'-DDT	ppb	4
alpha-BHC	ppb	4
a-Chlordane	ppb	4
Aldrin	ppb	4
beta-BHC	ppb	4
Chlordane, technical	ppb	40
delta-BHC	ppb	4
Dieldrin	ppb	4
Endosulfan I	ppb	4
Endosulfan II	ppb	4
Endrin	ppb	4
Endrin aldehyde	ppb	4
Endrin ketone	ppb	4
Endosulfan Sulfate	ppb	4
gamma-BHC (Lindane)	ppb	4
g-Chlordane	ppb	4
Heptachlor	ppb	4
Heptachlor epoxide	ppb	4
Methoxychlor	ppb	10
Toxaphene	ppb	200
Volatile Organic Compounds - Method 8260B		
1,1,1,2-Tetrachloroethane	ppb	1
1,1,1-Trichloroethane	ppb	1
1,1,2,2-Tetrachloroethane	ppb	1
1,1,2-Trichloroethane	ppb	1
1,1-Dichloroethane	ppb	1
1,1-Dichloroethene	ppb	1
1,1-Dichloropropene	ppb	1
1,2,3-Trichlorobenzene	ppb	1
1,2,3-Trichloropropane	ppb	1
1,2,4-Trichlorobenzene	ppb	1
1,2,4-Trimethylbenzene	ppb	1
1,2-Dibromo-3-chloropropane	ppb	1
1,2-Dichloroethane	ppb	1
1,2-Dichlorobenzene	ppb	1
1,2-Dichloropropane	ppb	1
1,2-Dibromoethane	ppb	1
1,3,5-Trimethylbenzene	ppb	1

Table 2-5. (Continued)

Parameter	Units	Method Detection Limit BM-6 and BM-2
Volatile Organic Compounds - Method 8260B (Continued)		
1,3-Dichlorobenzene	ppb	1
1,3-Dichloropropane	ppb	1
1,4-Dichlorobenzene	ppb	1
2,2-Dichloropropane	ppb	1
2-Chlorotoluene	ppb	1
2-Hexanone	ppb	10
4-Chlorotoluene	ppb	1
Acetone	ppb	10
Benzene	ppb	1
Bromochloromethane	ppb	1
Bromodichloromethane	ppb	1
Bromobenzene	ppb	1
Bromoform	ppb	1
Bromomethane	ppb	1
c-1,2-Dichloroethene	ppb	1
c-1,3-Dichloropropene	ppb	1
Carbon Tetrachloride	ppb	1
Chlorobenzene	ppb	1
Chloroethane	ppb	1
Chloroform	ppb	1
Chloromethane	ppb	1
Methylene Chloride (DCM)	ppb	1
Dibromochloromethane	ppb	1
Dibromomethane	ppb	1
Dichlorofluoromethane	ppb	1
Ethylbenzene	ppb	1
Hexachloro1,3-butadiene	ppb	1
Isopropylbenzene (cumene)	ppb	1
m,p-Xylene	ppb	1
2-Butanone(MEK)	ppb	10
4-Methyl-2-pentanone (MIBK)	ppb	10
Methyl-tert-butylether (MTBE)	ppb	1
n-ButylBenzene	ppb	1
n-Propylbenzene	ppb	1
Naphthalene	ppb	1
o-Xylene	ppb	1
p-Isopropyltoluene	ppb	1
Tetrachloroethene	ppb	1
sec-Butylbenzene	ppb	1
Styrene	ppb	1
t-1,2-Dichloroethene	ppb	1
t-1,3-Dichloropropene	ppb	1
t-Butylalcohol	ppb	10
Trichloroethene	ppb	1
Toluene	ppb	1
Trichlorofluoromethane	ppb	1
Vinyl chloride	ppb	1

Table 2-6. Analytical methods, method detection limits, and sample hold times for arsenic and iron monitoring in sediments and water at Blue Marsh Reservoir in 2002				
Parameter	**EPA Method**	**Method Detection Limit**	**Allowable Hold Times (days)**	**Maximum Hold Time Achieved (days)**
Bottom Water (mg/L)				
Arsenic, dissolved	6010B	0.01	183	30
Iron, dissolved	6010B	0.002	183	30
Arsenic, total	6010B	0.01	183	30
Iron, total	6010B	0.005	183	30
Sediments (mg/kg)				
Arsenic, total	6010B	3.607/0.231	183	30
Iron, total	6010B	0.721/0.069	183	30

2.9 TREND ANALYSIS METHODS

Annual water quality, sediment contaminant, and drinking water monitoring have been conducted at Blue Marsh Reservoir since 1980. Data collected over these years were compiled into an electronic database by the USACE (Versar 1996). Similarly, water column stratification monitoring of temperature, dissolved oxygen, pH, and conductivity has been conducted by USACE personnel bi-monthly during spring and summer seasons since 1988. Electronic copies of these data were also compiled into a separate database.

The compilation of historical data enables the use of statistical trend analysis, an important step toward understanding how the water quality of Blue Marsh Reservoir is changing. A number of trend analysis methods are available, some more complicated than others. For the purposes of this report, we employed two general methods, regression and the Mann-Kendall or seasonal Kendall test.

2.9.1 Regression Analysis

The spatial and temporal distributions of the historical data were examined to determine which stations and parameters had sufficient time series to warrant meaningful trend analysis. For the major water quality parameters (e.g., nutrients, dissolved oxygen, total dissolved solids), downstream station BM-1 and reservoir stations BM-2, BM-3, BM-4, and BM-5, BM-6 and BM-9 were consistently sampled over the entire 20-year time span. In the 1980s, monthly sampling was conducted over the entire year, while only spring and summer sampling was conducted in the 1990s. Water quality trend analyses were therefore limited to spring (April through June) and summer (July through October) seasons. The "spring season" analyses were conceptualized as representing long-term trends associated with inputs to the reservoir system during snow melt periods. The "summer season" analyses depicted conditions during periods of maximum productivity and greatest low DO stress. Trends at station BM-1 were analyzed separately to evaluate conditions in Tulpehocken Creek downstream of the dam. Water quality trends within the reservoir were evaluated by averaging concentrations among surface water stations BM-2, BM-3, BM-4, and BM-5, BM-6 and BM-9. Regression analyses were used to determine if significant increases or decreases in parameter concentrations occurred during the time series. The slope of the regression line was used to estimate the yearly rate of change. For this report, regression analysis was applied to the water quality parameters: dissolved oxygen, ammonia, total nitrogen, total phosphorus, total dissolved solids, biochemical oxygen demand, and total and fecal coliform.

Monitoring of arsenic concentrations in water and sediments of Blue Marsh Reservoir was instituted in 1980 to address potential environmental effects of a hazardous waste site located 18 miles upstream on Tulpehocken Creek. Trends in arsenic concentration in the water and sediments were evaluated using regression analysis.

2.9.2 Mann-Kendall Analysis

In addition to the regression analysis, the non-parametric Mann-Kendall test was used to determine trends for individual stations over the time span of historical monitoring at Blue Marsh Reservoir. The Mann-Kendall test (or Seasonal Kendall test) scores all combinations of yearly changes for the tested parameter with a +1 or -1 depending on whether parameter concentrations increased or decreased over the time interval. All of the scores are then summed and compared to the Chi-Square distribution to determine if the parameter shows a significant trend (increasing or decreasing) over the time series. For this report, the Mann-Kendall test was applied to the water quality parameters: dissolved oxygen, ammonia, total nitrogen, total phosphorus, total dissolved solids, biochemical oxygen demand, and total and fecal coliform.

2.10 DRINKING WATER MONITORING

Drinking water was monitored at the public water fountain in the overlook building of Blue Marsh Reservoir (Table 2-1). Drinking water parameters were divided into two sets, A and B. Set A comprised bacteria parameters, total and fecal coliform (for analytical methods, see section 2.4), and nitrate and nitrite. Set A samples were collected on 13 March, 18 June, 19 August, and 10 October. Set B samples were analyzed for primary and secondary contaminants, and were collected on 13 March and 19 August. Table 2-7 summarizes analytical methods, detection limits, and samples hold times for Set B parameters, and nitrate and nitrite. All of the drinking water quality parameters were analyzed within their respective maximum allowable hold times.

Table 2-7. Analytical methods, method detection limits and sample hold times for primary and secondary drinking water contaminants monitored at Blue Marsh Reservoir in 2002				
Parameter	**Detection Limits (mg/L)**	**Method**	**Allowable Hold Times (Days)**	**Maximum Hold Time Achieved (Days)**
Aluminum	0.025	200.7	183	6
Antimony	0.024	200.7	183	6
Arsenic	0.018	200.7	183	6
Barium	0.005	200.7	183	6
Cadmium	0.001	200.7	183	6
Chromium	0.006	200.7	183	6
Copper	0.002	200.7	183	6
Iron	0.005	200.7	183	6
Lead	0.01	200.7	183	6
Magnesium	0.02	200.7	183	6
Manganese	0.002	200.7	183	6
Mercury	0.0002	245.1	28	7
Nickel	0.003	200.7	183	6
Selenium	0.02	200.7	183	6
Silver	0.003	200.7	183	6
Sodium	0.02	200.7	183	6
Thallium	0.063	200.7	183	6
Zinc	0.003	200.7	183	6
Chloride	0.5	300	28	2
Cyanide, free	0.009	SM4500CN-I	14	10
Fluoride	0.1	300	28	2
Foaming Agents	0.01	SM5540C	2	1
Nitrate	0.5	300	2	2
Nitrite	0.5	300	2	2
PH	0.01	150.1	N/A	0
Sulfate	5	300	28	2
Total Dissolved Solids @ 180 ºC	10	160.1	7	1
* pH measured on a logarithmic scale.				

3.0 RESULTS AND DISCUSSION

3.1 STRATIFICATION MONITORING

The following sections summarize the results of water quality monitoring for physical and chemical parameters: temperature, dissolved oxygen, pH, and conductivity. For each parameter, we describe seasonal and spatial patterns of surface water quality measured throughout the reservoir watershed, and seasonal and depth related patterns of the stratified water column based on measures from the deepest portion of the reservoir (station BM-6 or the "Tower"). We feel that it is appropriate to focus discussion of stratification on station BM-6 as water quality problems related to depth are generally most severe in deep water habitats, thus our evaluation will be a conservative one. Finally, we analyze 2002 data along with the Blue Marsh Reservoir historical database for trends in dissolved oxygen concentrations over the past 14 years. Versar personnel collected the physical/chemical water quality data discussed herein over the monitoring period from May to October 2002. All of the parameters were measured with a calibrated Hydrolab water quality meter and are presented in Appendix Table A.

3.1.1 Temperature

Temperature in surface waters of Blue Marsh Reservoir and most of its upstream tributaries followed a uniform pattern during 2002. At most stations, temperatures increased from approximately 19 °C in May and June to 29 °C from July to August, and thereafter decreased to 20 °C by October (Fig. 3-1). With the exception of July, surface water temperature upstream of the reservoir on Tulpehocken Creek (station BM-5) also followed a similar pattern but was consistently several degrees cooler than at other stations. Temperature at station BM-5 increased linearly from 12 °C in May to 30 °C in July, and dropped to 16 °C in October (Fig. 3-1). Surface water temperatures downstream of the reservoir (station BM-1) were also lower and fairly consistent throughout the monitoring period. From May to October, temperatures at this station ranged from 15 to 25 °C (Fig. 3-1).

Blue Marsh Reservoir was stratified with respect to temperature during 2002. The stratification pattern was most apparent at station BM-6 or the "Tower" Station located in the deepest part of the reservoir (Fig. 3-2). By mid-May, the pattern was already in place in the water column. In this month, temperature was greatest at the surface to a depth of 20-ft (16 °C), and thereafter gradually decreased to the bottom (10.5 °C). The patterns in June and July were similar, but warmer throughout the water column. By early August, temperature in the upper water column had reached its highest temperature at about 29.8 °C. In the lower water column, temperature increased from July into August but reached its highest values in October. In this latter month, the overall uniformity of the

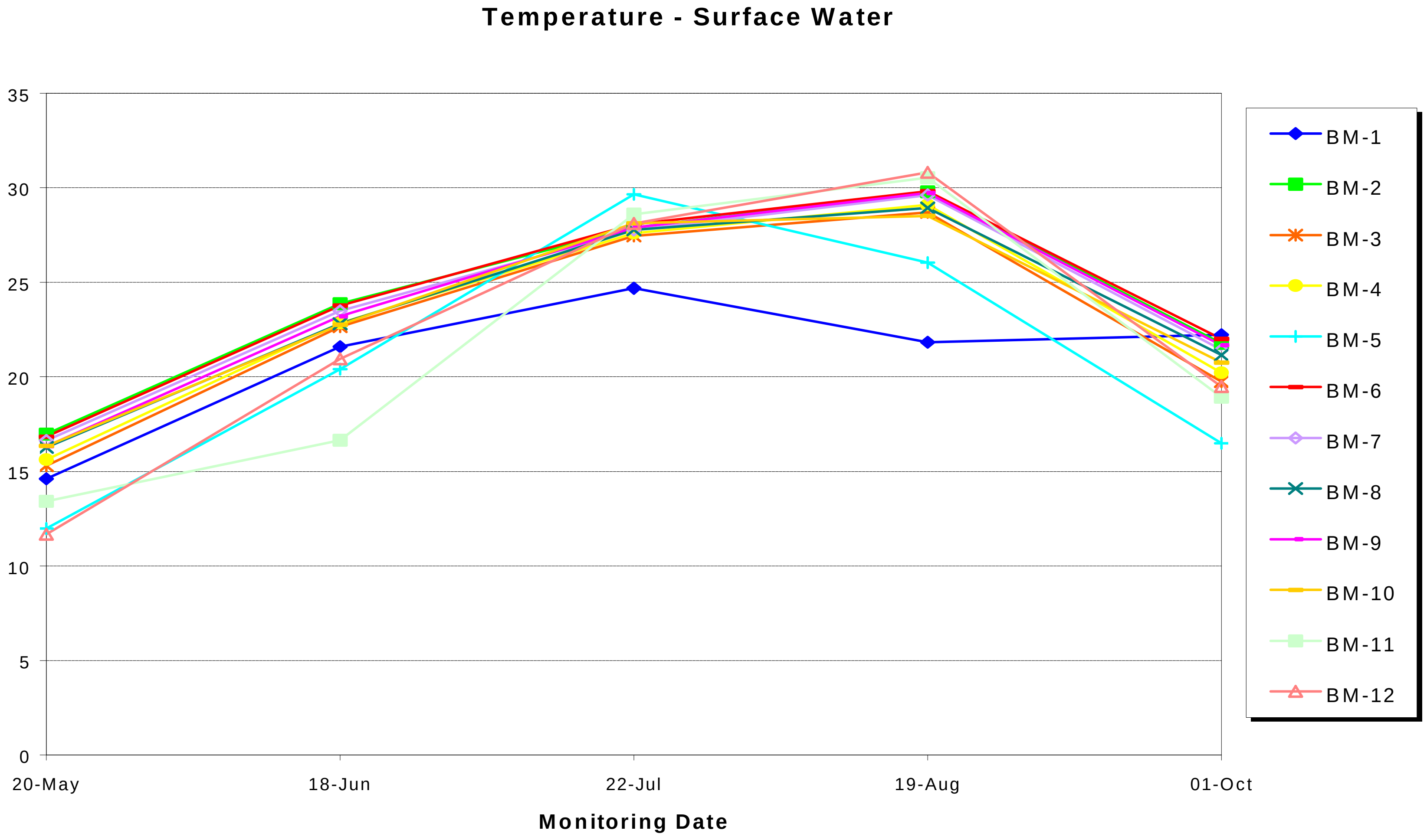

Figure 3-1. Surface water temperature (°C) measured at Blue Marsh Reservoir in 2002. See Appendix A for summary of plotted values.

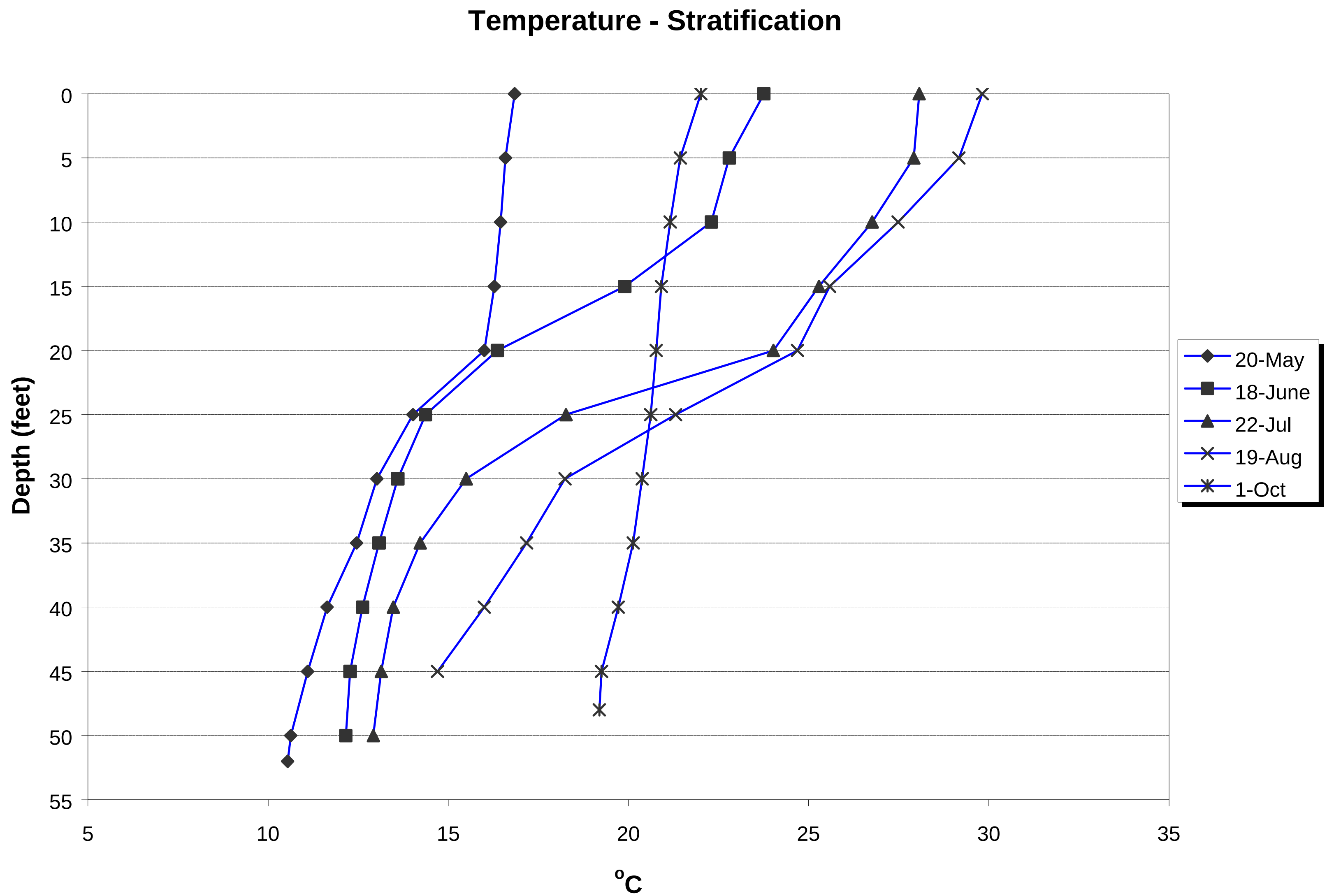

Figure 3-2. Temperature stratification at station BM-6 of Blue Marsh Reservoir in 2002. See Appendix A for summary of plotted values.

water column suggested the forthcoming fall turnover. By October, the entire water column was uniform, at about 20.5 °C.

3.1.2 Dissolved Oxygen

Dissolved oxygen (DO) in the surface waters of Blue Marsh Reservoir was predominantly uniform during 2002 (Fig. 3-3). Concentrations measured at most stations averaged 8.8-mg/L in May and June. DO in July averaged 10.5-mg/L and ranged from 8 and 15-mg/L, with the exception of BM-5. DO at BM-5 in July could not be recorded because the percent saturation level was higher than the instrumental range of the meter, which is 200%, probably due to algal production of oxygen. DO averaged 11.2-mg/L in August, and ranged between 6.6 and 15-mg/L. Concentrations were varied in October but averaged 7.7-mg/L. DO was highest at the shallow stations BM-3 (Spring Creek) and BM-4 (Licking Creek), averaging 11-mg/L throughout the monitoring period.

The stratification of Blue Marsh Reservoir dramatically influenced the distribution of DO in the water column during 2002 (Fig. 3-4). Even as early as May, the influence of stratification was apparent at station BM-6, as DO concentrations decreased from 8.6-mg/L at the surface to 0-mg/L near the bottom. By June and continuing into October, the lower water column from 10-15 feet to the bottom was severely depleted of oxygen with concentrations less than 2-mg/L. Surface concentrations in those months remained at about 8.75-mg/L. In October, concentrations of DO at the surface decreased to 4.75-mg/L while concentrations of DO in the lower water column remained low.

DO concentrations in the lower water column of Blue Marsh Reservoir were not in compliance with PADEP water quality standards from May to October. The Pennsylvania water quality standard for DO is a minimum concentration of 5 mg/L. In May, DO at station BM-6 from 20 feet to the bottom dropped below the standard (Fig. 3-4). From June to October more than half of the water column was less than the standard. In October the entire water column was below the DO standard.

The health of aquatic ecosystems can be impaired by low DO concentrations in the water column. Hypoxia, or conditions of DO concentrations less than 2 mg/L, is generally accepted as the threshold at which the most severe effects on biota occur. In 2002, the lower water column of Blue Marsh was severely affected by hypoxia (Fig. 3-5). Hypoxic water was encountered in the months from May to October and commonly occupied more than half of the water column from 10 to 30-ft to the bottom. Hypoxia in the lower water column is a symptom of eutrophication. Nutrients in the water column feed explosive algal growth at the surface photic zone. Dead and decaying algae sink to lower levels of the water column and during the process of decay; oxygen is removed from the water column.

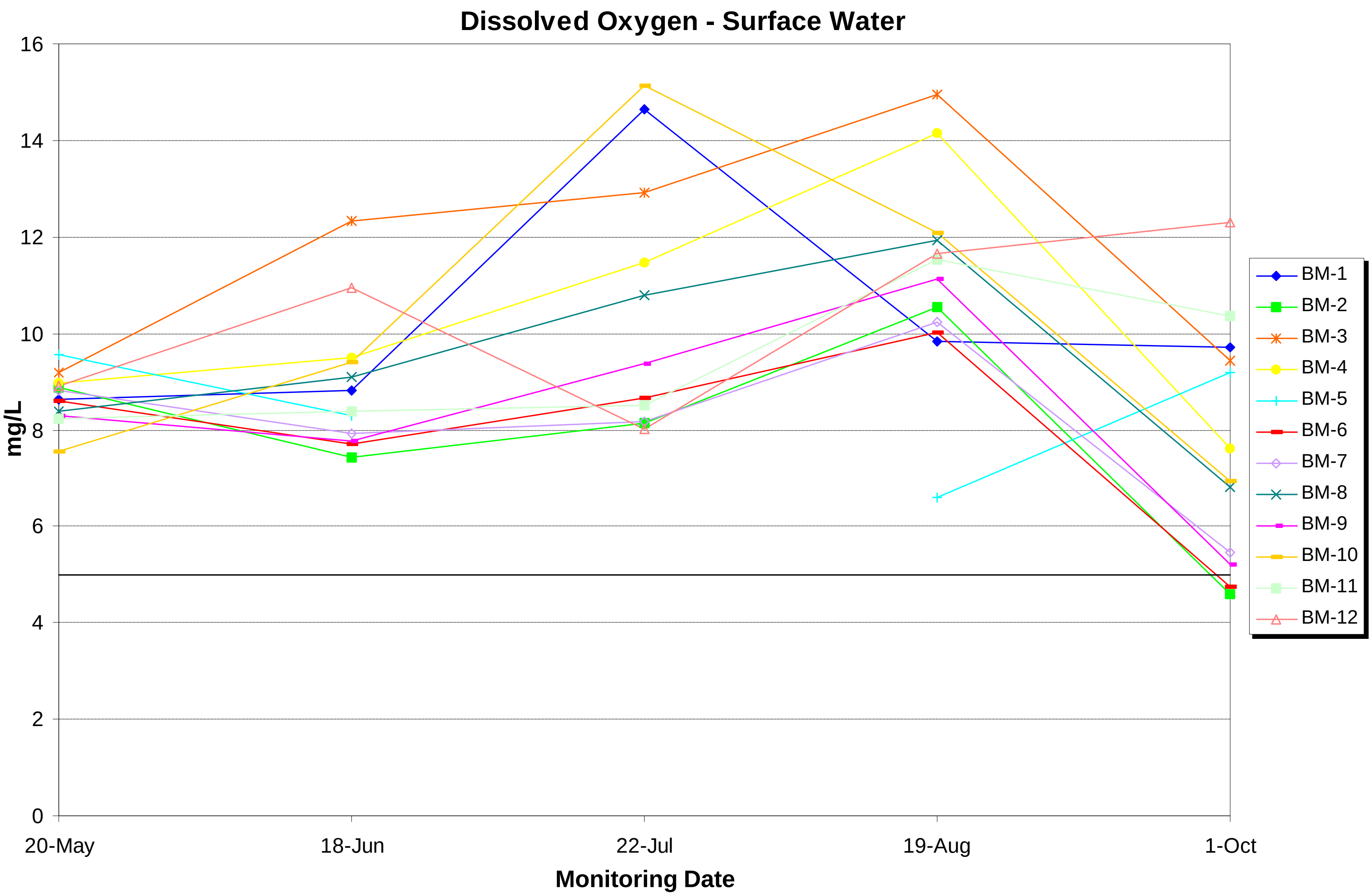

Figure 3-3. Surface water dissolved oxygen concentrations measured at Blue Marsh Reservoir in 2002. (The PADEP water quality standard for DO is a minimum concentration of 5 mg/L.) See Appendix A for summary of plotted values.

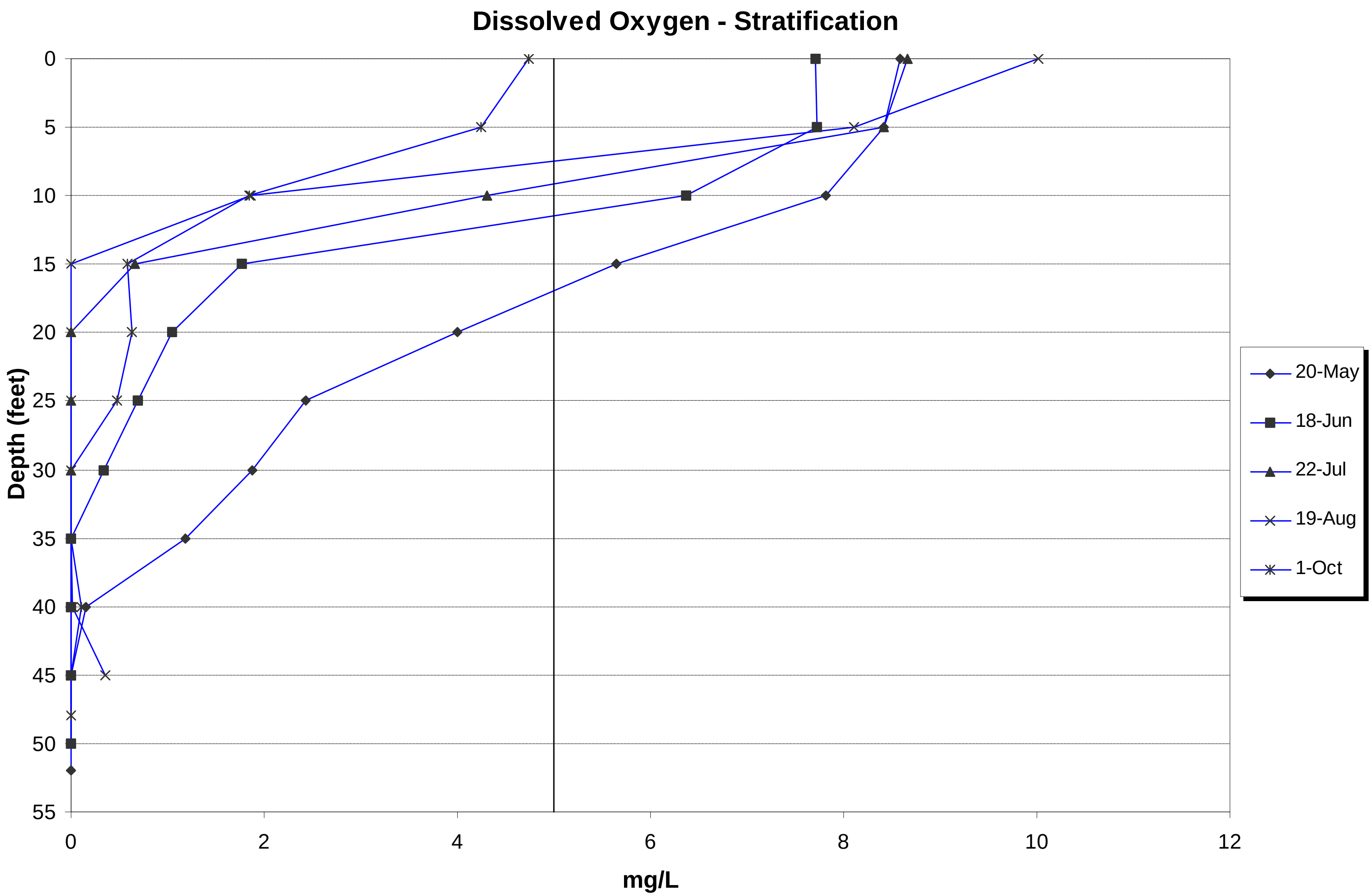

Figure 3-4. Dissolved oxygen stratification at station BM-6 of Blue Marsh Reservoir in 2002. (PADEP water quality standard for DO is a minimum concentration of 5 mg/L.) See Appendix A for summary of plotted values. 7 June DO data were missing from the USACE database.

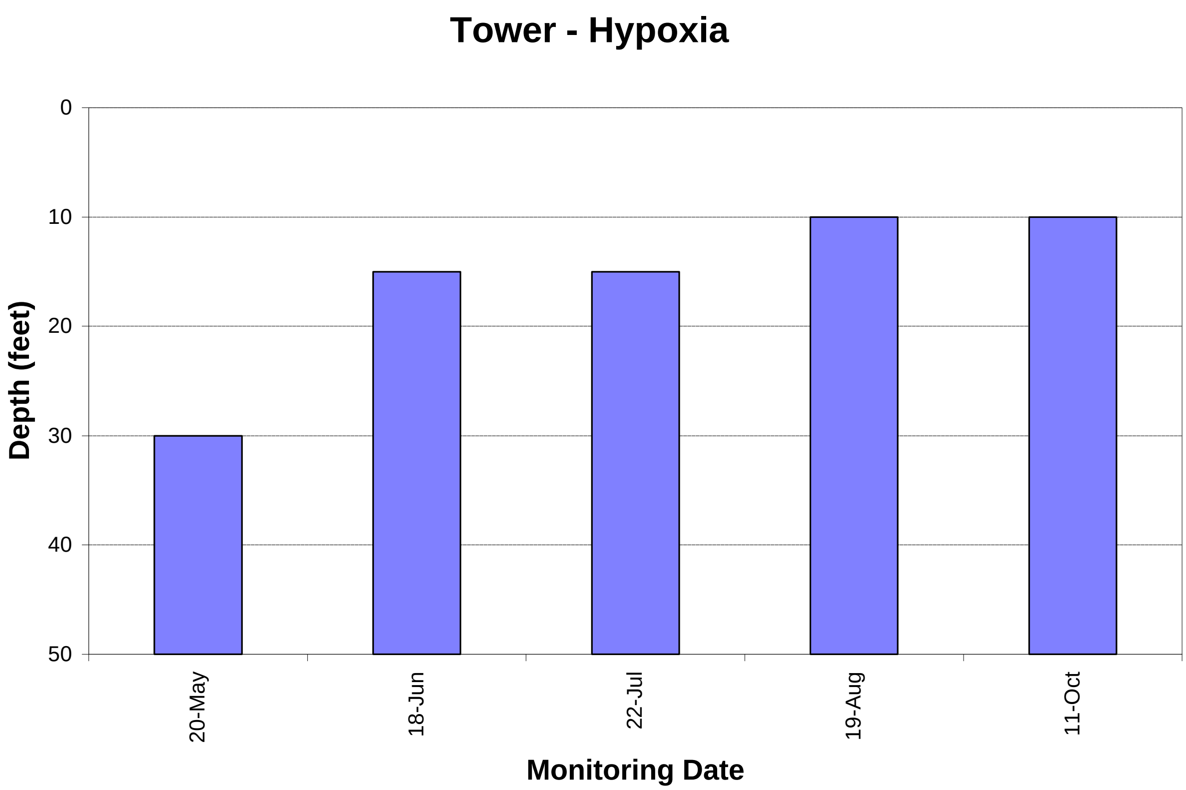

Figure 3-5. Spatial/temporal distribution of hypoxic reservoir water in Blue Marsh Reservoir measured at the "Tower" station in 2002. Histograms indicate dissolved oxygen concentrations in the water column below 2.0 mg/L.

Analyzing historical data provides a means of characterizing water quality trends at Blue Marsh Reservoir. Dissolved oxygen concentrations have been measured in the water column near the "Tower," or station BM-6, since 1988. Since 1996 Versar, Inc. has analyzed the historical data for trends on water quality based on the depth in the water column at which hypoxia occurs. The trends were determined for two seasonal periods: spring, comprising the months from April to June, and summer, from July to October. No significant trends resulted from the regression analysis for dissolved oxygen concentration over the 14-year period (Fig. 3-6). Neither regression line for spring or summer concentrations of DO were significant ($P < 0.05$), although a consistent difference in the depth of encountering hypoxia was apparent between the two seasons. The depth at which hypoxia was typically observed during summer was about 11 feet higher in the water column than for spring.

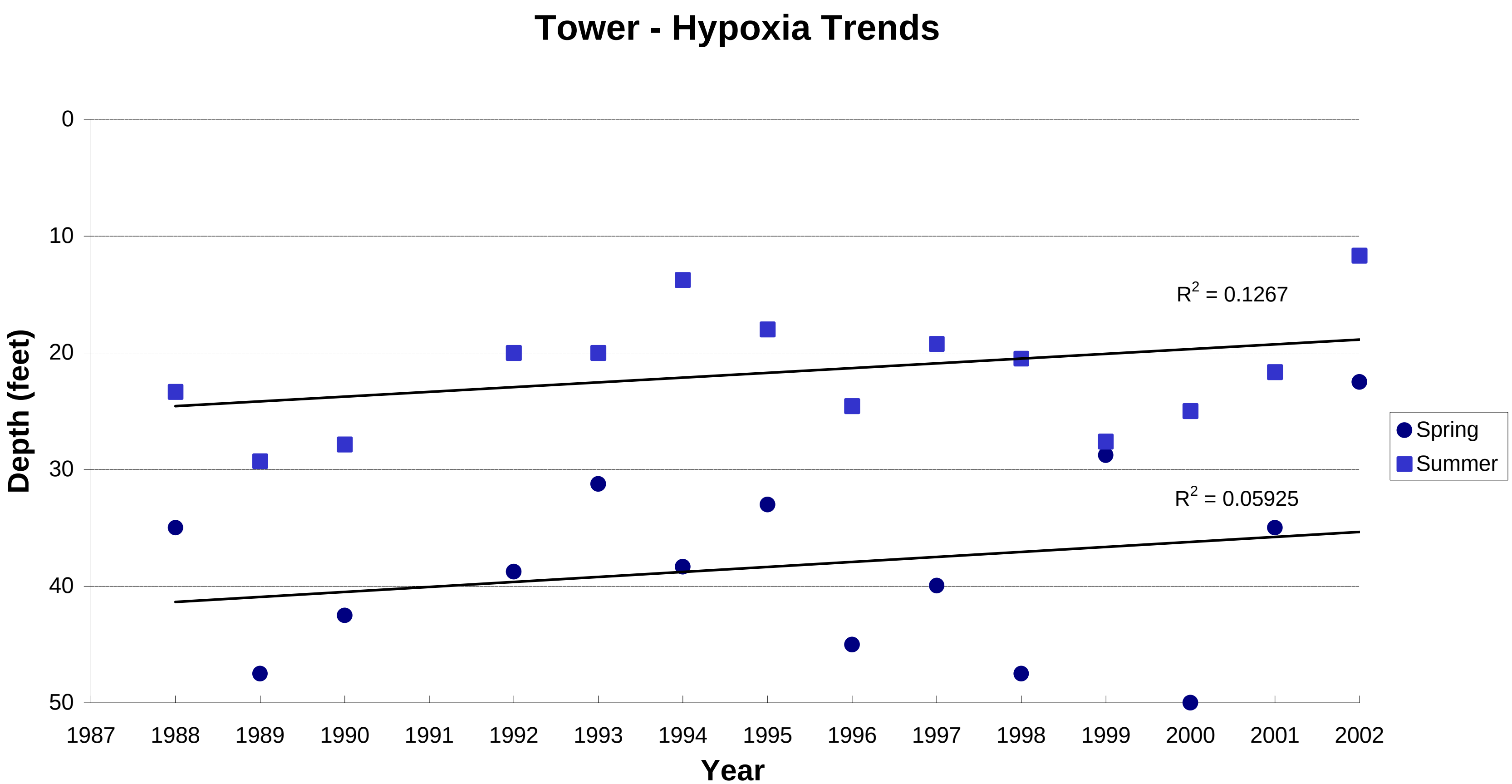

Figure 3-6. Trends in seasonal average hypoxia at the "Tower" station, BM-6. Regression is based on the depth at which hypoxia was observed in the water column.

Mann-Kendall test was used to determine if DO concentrations had significantly changed at individual monitoring stations over the course of the historical monitoring of Blue Marsh Reservoir. The test was conducted individually on spring and summer season data at stations having sufficient historical data. Surface water concentrations were analyzed at upstream tributary stations BM-3, BM-4, BM-5 and downstream station BM-1. Surface and bottom water concentrations were averaged at stations in the main-body of the reservoir (BM-2, BM-6, and BM-9).

Significant trends were determined from the analysis on upstream stations BM-3 and BM-4 for the spring. Additionally, it was determined that BM-3 had a significant increasing trend in the summer (Table 3-1). Overall, the greatest rate of increase among all stations was estimated for surface station BM-3 at 0.33-mg/L for the summer season. A significant decreasing trend at a rate of 0.18-mg/L was also observed in the surface and bottom waters for the summer at station BM-9.

Table 3-1. Seasonal trends of dissolved oxygen concentration at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant (at least $P < 0.05$).

Station	# of Years	Spring		Summer	
		P Level	Rate (mg/L)	P Level	Rate (mg/L)
Surface Water					
BM-1	21	NS	0.0102	NS	-0.0112
BM-3	21	<0.001	0.2764	<0.001	0.3275
BM-4	21	<0.05	0.2130	NS	0.1897
BM-5	21	NS	0.0146	NS	-0.005
Surface and Bottom Water					
BM-2	18	NS	-0.1331	NS	-0.0111
BM-6	18	NS	-0.1098	NS	-0.0112
BM-9	17	NS	-0.2314	<0.05	-0.1801

3.1.3 pH

Measures of pH in the surface waters of Blue Marsh Reservoir and its upstream tributaries followed a similar pattern during 2002 (Fig. 3-7). In May, pH was lowest with measures at most stations at about 7.9. For the remainder of the monitoring period, pH ranged higher from 7.4 to 9.3. Stations BM-5 and BM-10 exceeded the PADEP water quality standard maximum of 9 in July and BM-3 exceeded the standard in August. Measures of pH downstream of the reservoir (station BM-1) and upstream station BM-11 were consistently lower than in other parts of the reservoir. Measures at these 2 stations generally ranged from 7.3 to 8.8 throughout the monitoring period. Stations BM-11 is located downstream of the Bernville Wastewater Management Facility and may have been

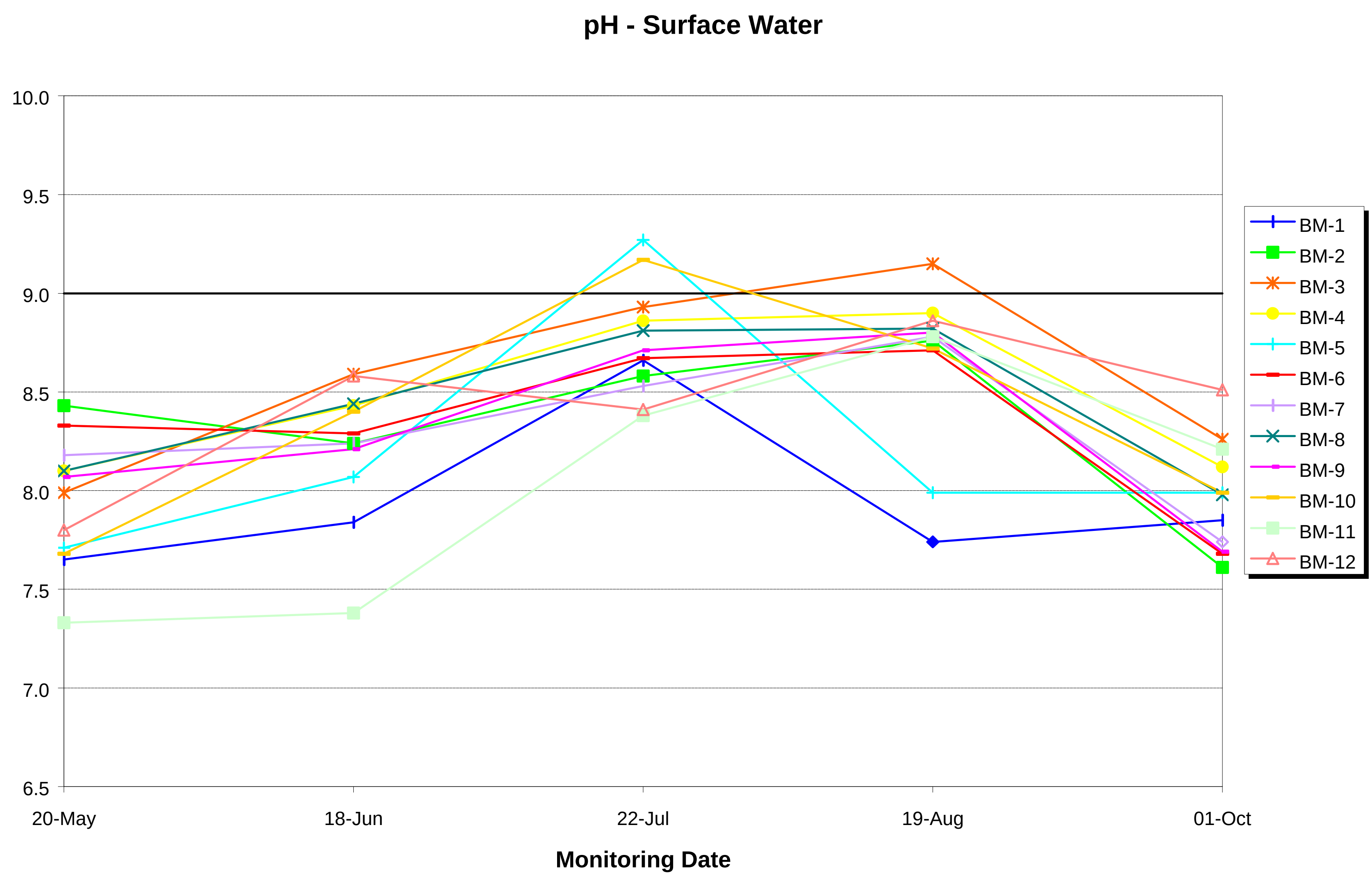

Figure 3-7. Surface water pH measured at Blue Marsh Reservoir in 2002. (The PADEP water quality standard for pH is a range from 6 to 9.) See Appendix A for summary of plotted values.

effected by their effluent discharges. Downstream pH measured at station BM-1 was likely influenced by dam releases from the lower water column.

Stratification of pH in the water column of Blue Marsh Reservoir was present during 2002 (Fig. 3-8). Throughout the monitoring period the upper water column had higher pH measures than the lower. Higher pH in the upper euphotic zone was probably caused by algal activity. During photosynthesis, algae remove CO_2 from surface waters that results in an increase of pH in soft-water systems. During most months, pH at the surface to a depth of 10-ft ranged between 7.4 and 8.7. In contrast, measures of pH in the lower water column were consistently lower during the monitoring period at approximately 7.3.

3.1.4 Conductivity

Conductivity in surface waters of Blue Marsh Reservoir and most of the upstream tributaries generally followed a similar pattern in 2002 (Fig. 3-9). At most stations, conductivity averaged approximately 0.34 mS/cm throughout the monitoring period and ranged from 0.16 to 0.59 mS/cm. Conductivity measured upstream on Tulpehocken Creek (station BM-5) was consistently greater, throughout the monitoring period. Measures of conductivity at station BM-5 ranged from 0.32 to 0.59 mS/cm. Conductivity was also slightly higher downstream of the reservoir (station BM-1). Throughout the monitoring period measures at station BM-1 averaged 0.36 mS/cm and ranged from 0.35 to 0.38 mS/cm.

Conductivity in the water column of Blue Marsh Reservoir was influenced by stratification during 2002 (Fig. 3-10). In general, conductivity in the lower water column appeared to increase with depth over the course of the monitoring period. In May, the water column was averaged about 0.33 mS/cm. From June to October, the difference between the upper and the lower water column progressively increased. At the height of summer in August, conductivity at the surface was 0.31-mS/cm while that at the bottom was 0.41-mS/cm. This pattern is indicative of the reducing conditions of the hypoxic environment present in the lower water column enabling more metals to be mobilized from bottom sediments.

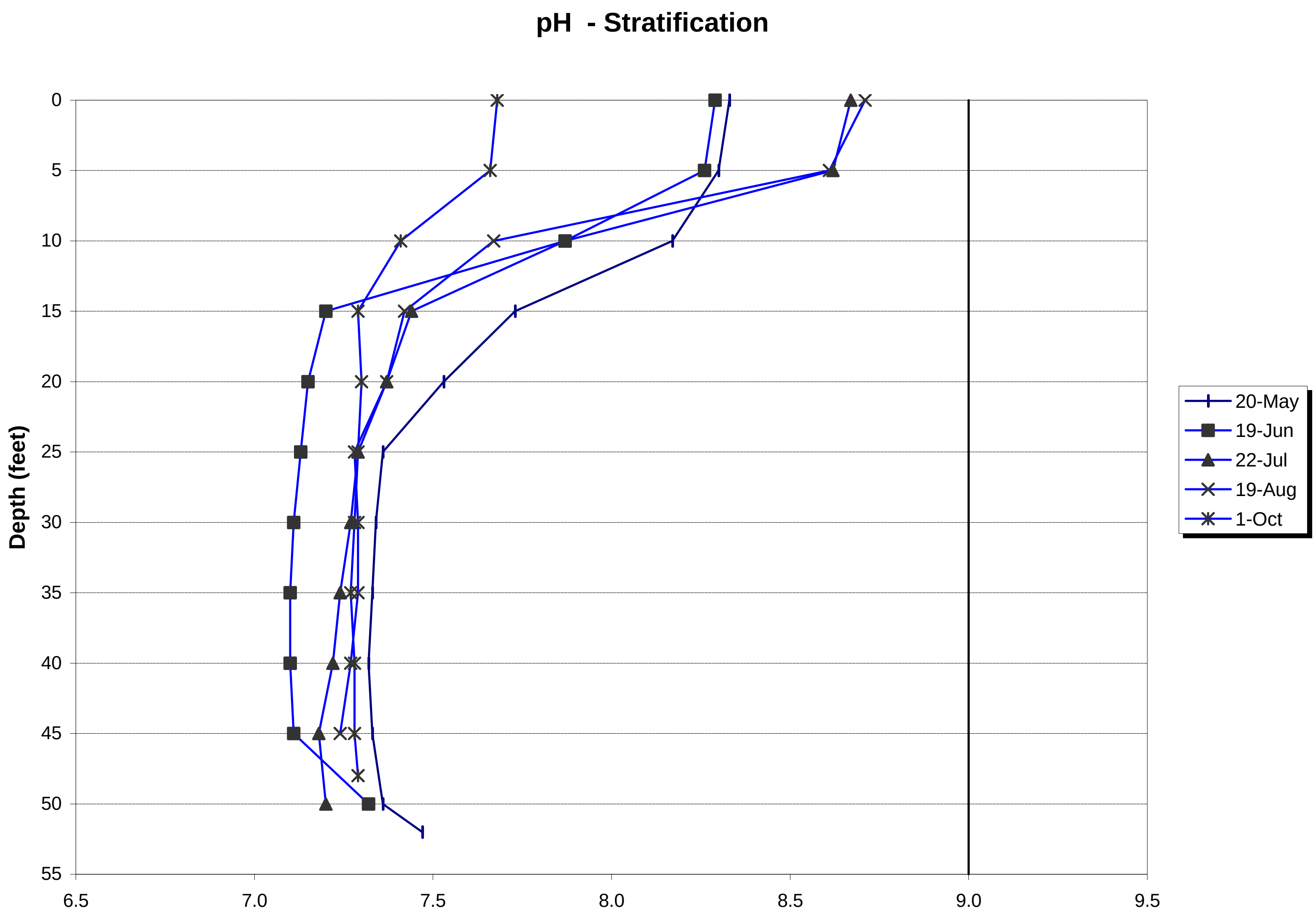

Figure 3-8. pH stratification at station BM-6 of Blue Marsh Reservoir in 2002. (The PADEP water quality standard for pH is a range from 6 to 9.) See Appendix A for summary of plotted values.

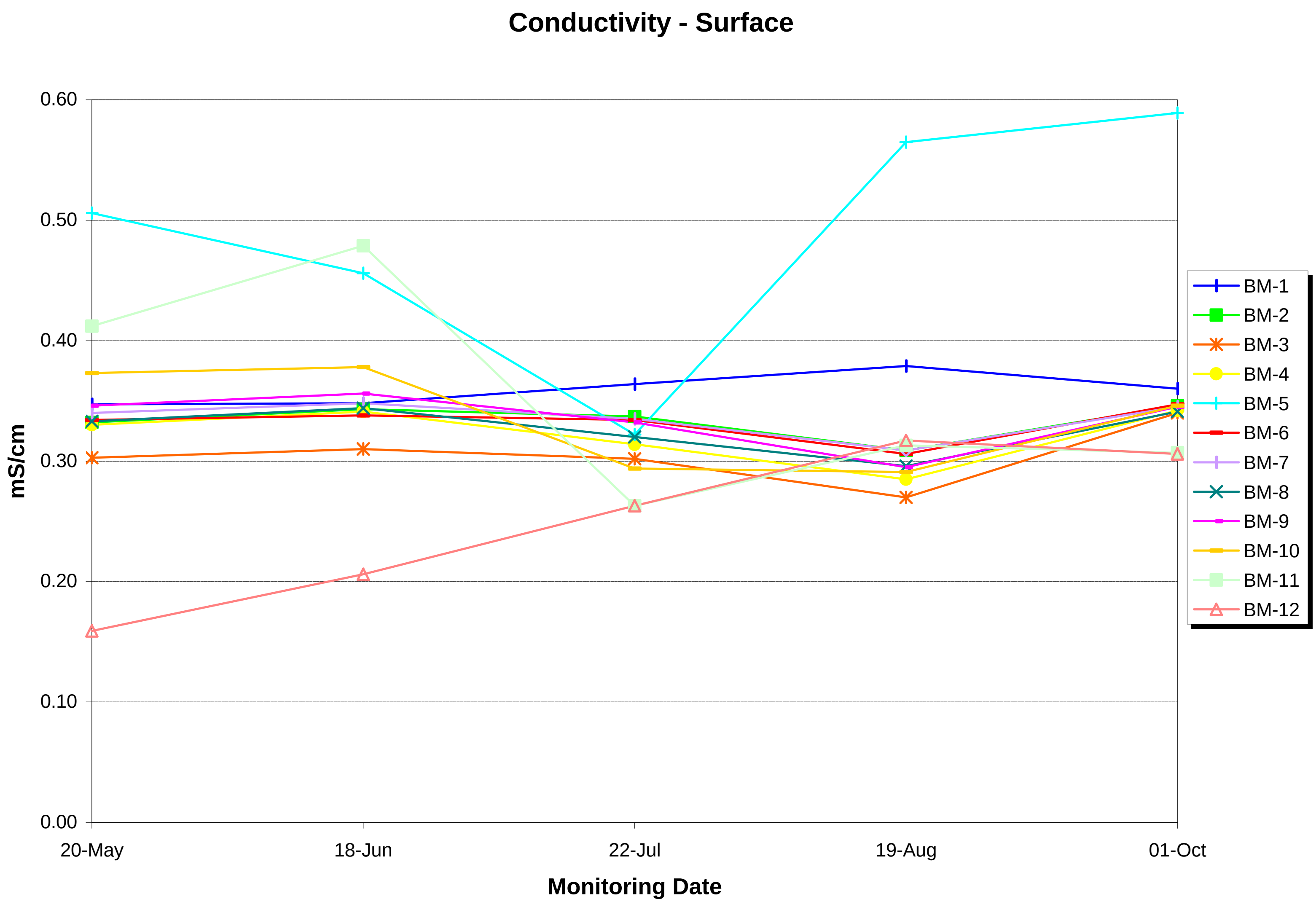

Figure 3-9. Surface water conductivity (mS/cm) measured at Blue Marsh Reservoir in 2002. See Appendix A for summary of plotted values.

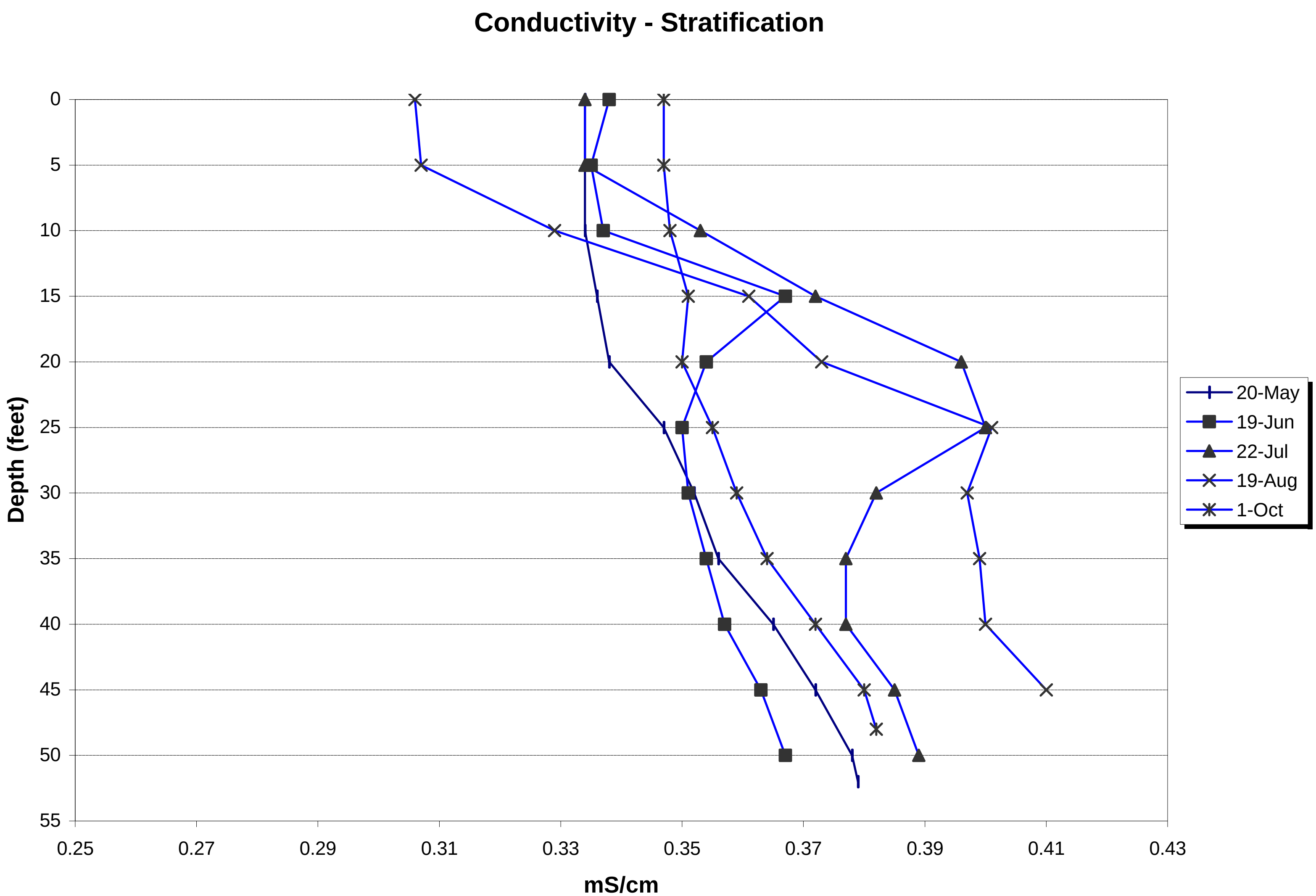

Figure 3-10. Conductivity stratification at station BM-6 of Blue Marsh Reservoir in 2002. See Appendix A for summary of plotted values.

3.2 WATER COLUMN CHEMISTRY MONITORING

The following sections describe temporal, spatial, and depth patterns for the water quality parameters measured in surface, middle, and bottom waters of Blue Marsh Reservoir during 2002 (Table 3-2). Where appropriate, long-term trends are discussed for surface water quality parameters incorporating 2002 data with the Blue Marsh Reservoir historical water quality database.

3.2.1 Ammonia

In general, ammonia remained low in the upper middle water column of Blue Marsh Reservoir but was higher in the lower column (Fig. 3-11). Concentrations measured in most surface and middle waters of the reservoir (BM-2, -6, -7, -8, -9, and -10) and surface waters upstream of the reservoir (BM-3, -4, -5, -11, and -12) averaged 0.19 mg/L and at most ranged to 0.77 mg/L (BM-7 at the surface in June). Ammonia in the lower water column was distinctly higher. Concentrations at stations BM-2, -6, and -9 averaged 0.81 mg/L and ranged as high as 2.45 mg/L (BM-9 in August). Concentration in bottom waters of remaining parts of the reservoir (stations BM-7, -8, and -10) averaged 0.52 mg/L. Concentrations measured downstream of the reservoir (BM-1) were for the most part low, with a maximum value of 0.3 mg/L during August.

Concentrations of ammonia measured at Blue Marsh Reservoir were not in compliance with PADEP water quality standards during 2002. The state water quality standard for ammonia is dependent on temperature and pH (Table 3-3). Specific criteria were calculated for all measures of ammonia based on the temperature and pH at the time of sampling (measured with a Hydrolab). Concentrations of ammonia exceeded the calculated criteria at three surface stations during monitoring period. BM-5 and BM-10 both exceeded the calculated criteria during July and BM-3 exceeded the calculated criteria during August.

Seasonal trends for ammonia (spring and summer) were determined for individual monitoring stations using the non-parametric Mann-Kendall Statistic. Ammonia in surface water from upstream sources appears to have decreased over the past two decades (Table 3-4). A significant summer trend was calculated for station BM-3, -0.0169 mg/L/year. The greatest rate of decrease was seen downstream at BM-1 and had a rate of decrease of 0.0194 mg/L/year. A significant increase of 0.0196 mg/L/year was noted for station BM-2 in the spring.

Table 3-2. Summary of surface, middle, and bottom water quality monitoring data for Blue Marsh Reservoir in 2002

STATION	DATE	NH3	NO2	NO3	PO4	TKN	TP	TDS	TSS	BOD5	ALK	CHL_A	DISS_P
BM-1S	20-May	0.10	0.033	3.22	0.27	1.0	0.12	180	2	< 2	106	5.0	0.09
	18-Jun	0.11	2.500	1.00	0.14	1.0	0.05	180	3	2	106	2.0	0.05
	22-Jul	0.15	< 0.010	2.45	0.05	1.3	0.02	196	4	< 2	112	3.5	0.02
	19-Aug	0.29	< 0.010	6.16	0.08	1.2	0.04	214	4	2	140	2.9	0.03
	01-Oct	0.12	< 0.010	1.71	0.15	1.4	0.08	199	< 1	2	110	2.4	0.05
Mean		0.15	0.513	2.91	0.14	1.2	0.06	194	3	2	115	3.2	0.05
Maximum		0.29	2.500	6.16	0.27	1.4	0.12	214	4	2	140	5.0	0.09
Minimum		0.10	0.010	1.00	0.05	1.0	0.02	180	1	2	106	2.0	0.02
Std. Dev		0.08	1.111	2.00	0.08	0.2	0.04	14	1	0	14	1.2	0.03
No. of D		5	2	5	5	5	5	5	4	3	5	5	5
BM-2S	20-May	< 0.05	0.021	3.36	0.10	0.7	0.04	170	2	< 2	98	5.5	0.03
	18-Jun	0.16	< 0.010	2.40	0.15	0.8	0.05	191	2	< 2	102	2.6	0.05
	22-Jul	0.14	< 0.010	2.33	0.01	1.2	< 0.01	165	< 1	< 2	92	7.6	< 0.01
	19-Aug	0.17	< 0.010	1.59	0.08	2.1	< 0.01	179	6	3	84	7.4	0.02
	01-Oct	0.62	< 0.010	0.89	0.07	1.8	0.04	180	1	2	100	3.6	0.02
Mean		0.13	0.169	1.81	0.16	0.8	0.08	137	11	3	71	5.3	0.03
Maximum		0.17	0.800	3.78	0.37	1.8	0.14	176	18	7	116	7.6	0.05
Minimum		0.10	0.010	0.48	0.05	0.3	0.03	92	7	2	28	2.6	0.01
Std. Dev		0.03	0.353	1.27	0.12	0.6	0.05	34	5	2	33	2.2	0.02
No. of D		5	2	5	5	5	5	5	5	3	5	5	4
BM-2M	20-May	< 0.05	0.029	3.46	0.06	0.5	0.03	194	2	< 2	98	3.8	0.02
	18-Jun	0.27	1.100	2.70	0.15	0.7	0.05	196	6	< 2	114	3.1	0.05
	22-Jul	0.33	< 0.010	2.26	0.05	1.1	0.04	162	75	3	94	6.6	0.02
	19-Aug	0.42	< 0.010	1.74	0.07	0.9	0.03	200	2	4	112	3.5	0.02
	01-Oct	0.36	< 0.010	1.01	0.09	1.6	0.12	176	5	2	100	2.6	0.03
Mean		0.29	0.232	2.23	0.08	1.0	0.05	186	18	3	104	3.9	0.03
Maximum		0.42	1.100	3.46	0.15	1.6	0.12	200	75	4	114	6.6	0.05
Minimum		0.05	0.010	1.01	0.05	0.5	0.03	162	2	2	94	2.6	0.02
Std. Dev		0.14	0.485	0.93	0.04	0.4	0.04	16	32	1	9	1.6	0.01
No. of D		4	2	5	5	5	5	5	5	3	5	5	5
BM-2B	20-May	0.40	0.043	2.81	0.23	0.5	0.13	210	101	< 2	118	8.0	0.07
	18-Jun	0.69	1.400	1.90	0.12	1.9	0.04	205	3	2	120	1.6	0.04
	22-Jul	1.46	< 0.010	0.70	0.45	1.5	0.09	201	10	6	142	1.8	0.05
	19-Aug	0.89	< 0.010	0.14	0.08	1.7	0.06	227	6	< 2	156	2.5	0.03
	01-Oct	0.67	< 0.010	1.61	0.21	1.6	0.09	198	13	3	114	3.2	0.07
Mean		0.82	0.295	1.43	0.22	1.4	0.08	208	27	3	130	3.4	0.05
Maximum		1.46	1.400	2.81	0.45	1.9	0.13	227	101	6	156	8.0	0.07
Minimum		0.40	0.010	0.14	0.08	0.5	0.04	198	3	2	114	1.6	0.03
Std. Dev		0.40	0.618	1.04	0.14	0.5	0.03	11	42	2	18	2.7	0.02
No. of D		5	2	5	5	5	5	5	5	3	5	5	5

Table 3-2. (Continued)

STATION	DATE	NH3	NO2	NO3	PO4	TKN	TP	TDS	TSS	BOD5	ALK	CHL_A	DISS_P
BM-3S	20-May	0.10	0.027	3.27	0.23	0.2	0.1	172	13	< 2	86	7.2	0.07
	18-Jun	0.06	1.100	2.20	0.23	1.3	0.08	173	9	4	86	6.7	0.07
	22-Jul	0.15	< 0.010	1.91	0.07	1.0	0.03	147	15	3	74	15.6	0.02
	19-Aug	0.17	< 0.010	1.09	0.08	0.8	0.04	144	19	6	62	7.3	0.02
	01-Oct	0.26	< 0.010	1.32	0.17	1.1	0.08	175	4	4	92	5.7	0.05
Mean		0.15	0.231	1.96	0.16	0.9	0.07	162	12	4	80	8.5	0.05
Maximum		0.26	1.100	3.27	0.23	1.3	0.10	175	19	6	92	15.6	0.07
Minimum		0.06	0.010	1.09	0.07	0.2	0.03	144	4	2	62	5.7	0.02
Std. Dev		0.08	0.486	0.86	0.08	0.4	0.03	15	6	1	12	4.0	0.03
No. of D		5	2	5	5	5	5	5	5	4	5	5	5
BM-4S	20-May	< 0.05	0.021	4.01	0.11	0.3	0.05	184	< 1	< 2	98	5.1	0.04
	18-Jun	0.10	< 0.010	2.20	0.19	0.8	0.06	183	5	2	106	4.3	0.06
	22-Jul	0.15	< 0.010	2.08	0.01	1.0	< 0.01	153	2	3	86	8.8	< 0.01
	19-Aug	0.17	< 0.010	1.46	0.07	0.5	0.02	159	12	6	68	10.3	0.02
	01-Oct	0.25	< 0.010	1.14	0.10	1.2	0.04	162	6	3	96	5.8	0.03
Mean		0.14	0.012	2.18	0.10	0.8	0.04	168	5	3	91	6.9	0.03
Maximum		0.25	0.021	4.01	0.19	1.2	0.06	184	12	6	106	10.3	0.06
Minimum		0.05	0.010	1.14	0.01	0.3	0.01	153	1	2	68	4.3	0.01
Std. Dev		0.08	0.005	1.11	0.07	0.4	0.02	14	4	2	15	2.6	0.02
No. of D		4	1	5	5	5	4	5	4	4	5	5	4
BM-5S	20-May	< 0.05	0.023	8.32	0.20	< 0.1	0.08	302	2	< 2	168	5.7	0.06
	18-Jun	0.10	1.400	4.00	0.42	1.2	0.14	282	39	2	164	2.8	0.14
	22-Jul	0.17	< 0.010	1.81	0.24	1.7	0.16	145	36	10	76	18.3	0.08
	19-Aug	0.21	< 0.010	4.41	1.00	5.3	0.35	288	50	< 2	194	9.9	0.32
	01-Oct	0.13	< 0.010	2.46	0.17	0.8	0.08	189	7	< 2	96	1.6	0.05
Mean		0.13	0.291	4.20	0.41	1.8	0.16	241	27	4	140	7.7	0.13
Maximum		0.21	1.400	8.32	1.00	5.3	0.35	302	50	10	194	18.3	0.32
Minimum		0.05	0.010	1.81	0.17	0.1	0.08	145	2	2	76	1.6	0.05
Std. Dev		0.06	0.620	2.54	0.35	2.0	0.11	70	21	4	51	6.8	0.11
No. of D		4	2	5	5	4	5	5	5	2	5	5	5
BM-6S	20-May	< 0.05	0.023	3.47	0.09	0.2	0.04	196	5	< 2	98	4.8	0.03
	18-Jun	0.10	1.200	2.30	0.12	0.8	0.04	197	3	< 2	96	2.7	0.04
	22-Jul	0.13	< 0.010	2.34	< 0.01	1.2	< 0.01	151	3	3	166	6.2	< 0.01
	19-Aug	0.18	< 0.010	2.77	0.08	1.8	< 0.01	157	7	4	82	8.8	0.02
	01-Oct	0.47	< 0.010	0.85	0.09	1.6	0.06	171	3	2	104	4.9	0.03
Mean		0.19	0.251	2.35	0.08	1.1	0.03	174	4	3	109	5.5	0.03
Maximum		0.47	1.200	3.47	0.12	1.8	0.06	197	7	4	166	8.8	0.04
Minimum		0.05	0.010	0.85	0.01	0.2	0.01	151	3	2	82	2.7	0.01
Std. Dev		0.17	0.531	0.96	0.04	0.6	0.02	21	2	1	33	2.2	0.01
No. of D		4	2	5	4	5	3	5	5	3	5	5	4

Table 3-2. (Continued)

STATION	DATE	NH3	NO2	NO3	PO4	TKN	TP	TDS	TSS	BOD5	ALK	CHL_A	DISS_P
BM-6M	20-May	0.10	0.021	3.55	0.08	0.3	0.03	194	6	< 2	116	4.8	0.03
	18-Jun	0.10	1.400	1.90	0.12	0.9	0.04	176	3	< 2	108	2.6	0.04
	22-Jul	0.26	0.600	2.38	0.03	0.9	0.02	205	6	5	122	2.8	0.01
	19-Aug	0.39	< 0.010	1.76	0.07	1.6	0.01	192	4	3	118	2.6	0.02
	01-Oct	0.62	< 0.010	0.89	0.09	3.7	0.04	172	3	3	102	3.6	0.03
Mean		0.29	0.408	2.10	0.08	1.5	0.03	188	4	3	113	3.3	0.03
Maximum		0.62	1.400	3.55	0.12	3.7	0.04	205	6	5	122	4.8	0.04
Minimum		0.10	0.010	0.89	0.03	0.3	0.01	172	3	2	102	2.6	0.01
Std. Dev		0.22	0.610	0.97	0.03	1.3	0.01	14	2	1	8	1.0	0.01
No. of D		5	3	5	5	5	5	5	5	3	5	5	5
BM-6B	20-May	0.10	0.046	2.47	0.14	0.3	0.06	218	4	< 2	104	3.8	0.05
	18-Jun	1.01	1.200	1.60	0.42	2.2	0.14	215	196	8	122	3.6	0.14
	22-Jul	0.76	0.150	1.45	0.08	1.0	0.03	193	7	5	126	9.2	0.03
	19-Aug	0.54	< 0.010	1.56	0.08	2.3	0.02	206	12	2	144	3.3	0.03
	01-Oct	0.56	< 0.010	1.51	0.17	1.7	0.06	178	4	3	112	1.6	0.05
Mean		0.59	0.283	1.72	0.18	1.5	0.06	202	45	4	122	4.3	0.06
Maximum		1.01	1.200	2.47	0.42	2.3	0.14	218	196	8	144	9.2	0.14
Minimum		0.10	0.010	1.45	0.08	0.3	0.02	178	4	2	104	1.6	0.03
Std. Dev		0.33	0.516	0.42	0.14	0.8	0.05	17	85	3	15	2.9	0.05
No. of D		5	3	5	5	5	5	5	5	4	5	5	5
BM-7S	20-May	< 0.05	0.034	3.80	0.09	0.1	0.04	188	2	2	102	4.8	0.03
	18-Jun	0.77	< 0.010	2.30	0.14	0.6	0.05	172	4	< 2	104	3.2	0.04
	22-Jul	0.17	< 0.010	2.29	0.03	0.9	0.01	162	1	3	88	15.8	0.01
	19-Aug	0.13	< 0.010	1.71	0.08	1.6	0.02	147	13	5	84	9.2	0.03
	01-Oct	0.38	< 0.010	0.94	0.09	1.5	0.04	174	3	3	106	3.6	0.03
Mean		0.30	0.015	2.21	0.09	0.9	0.03	169	5	3	97	7.3	0.03
Maximum		0.77	0.034	3.80	0.14	1.6	0.05	188	13	5	106	15.8	0.04
Minimum		0.05	0.010	0.94	0.03	0.1	0.01	147	1	2	84	3.2	0.01
Std. Dev		0.29	0.011	1.05	0.04	0.6	0.02	15	5	1	10	5.3	0.01
No. of D		4	1	5	5	5	5	5	5	4	5	5	5
BM-7M	20-May	< 0.05	0.031	3.74	0.11	0.2	0.05	188	2	3	98	5.5	0.04
	18-Jun	0.16	0.800	2.60	0.15	1.0	0.06	199	12	2	114	2.1	0.05
	22-Jul	0.20	< 0.010	2.25	0.05	1.0	0.04	166	4	2	100	5.0	0.02
	19-Aug	0.28	< 0.010	1.80	0.12	1.6	0.04	195	1	4	106	5.6	0.04
	01-Oct	0.36	< 0.010	2.17	0.10	1.4	0.05	174	< 1	3	102	3.9	0.03
Mean		0.21	0.172	2.51	0.11	1.0	0.05	184	4	3	104	4.4	0.04
Maximum		0.36	0.800	3.74	0.15	1.6	0.06	199	12	4	114	5.6	0.05
Minimum		0.05	0.010	1.80	0.05	0.2	0.04	166	1	2	98	2.1	0.02
Std. Dev		0.12	0.351	0.74	0.04	0.5	0.01	14	5	1	6	1.5	0.01
No. of D		4	2	5	5	5	5	5	4	5	5	5	5

Table 3-2. (Continued)

STATION	DATE	NH3	NO2	NO3	PO4	TKN	TP	TDS	TSS	BOD5	ALK	CHL_A	DISS_P
BM-7B	20-May	0.20	0.029	3.36	0.34	0.2	0.12	192	22	< 2	92	4.4	0.11
	18-Jun	0.29	1.100	2.30	0.15	1.6	0.05	195	3	2	118	2.2	0.05
	22-Jul	0.79	< 0.010	1.72	0.06	1.9	0.18	207	4	2	140	1.6	0.02
	19-Aug	0.85	10.430	0.67	0.14	2.3	0.04	220	8	2	144	4.4	0.04
	01-Oct	0.31	< 0.010	1.42	0.09	1.3	0.05	182	12	2	100	3.4	0.03
Mean		0.49	2.316	1.89	0.16	1.5	0.09	199	10	2	119	3.2	0.05
Maximum		0.85	10.430	3.36	0.34	2.3	0.18	220	22	2	144	4.4	0.11
Minimum		0.20	0.010	0.67	0.06	0.2	0.04	182	3	2	92	1.6	0.02
Std. Dev		0.31	4.560	1.01	0.11	0.8	0.06	15	8	0	23	1.3	0.04
No. of D		5	3	5	5	5	5	5	5	4	5	5	5
BM-8S	20-May	< 0.05	0.027	3.86	0.12	0.2	0.05	206	6	2	98	5.1	0.04
	18-Jun	0.10	1.100	2.40	0.13	0.9	0.05	182	4	2	96	4.7	0.04
	22-Jul	0.13	< 0.010	2.35	0.04	1.5	0.01	169	6	3	84	6.2	0.01
	19-Aug	0.16	< 0.010	1.46	0.08	1.2	0.03	165	10	4	84	9.5	0.02
	01-Oct	0.27	< 0.010	1.04	0.10	1.5	0.04	178	< 1	4	98	5.0	0.03
Mean		0.14	0.231	2.22	0.09	1.1	0.04	180	5	3	92	6.1	0.03
Maximum		0.27	1.100	3.86	0.13	1.5	0.05	206	10	4	98	9.5	0.04
Minimum		0.05	0.010	1.04	0.04	0.2	0.01	165	1	2	84	4.7	0.01
Std. Dev		0.08	0.486	1.08	0.04	0.5	0.02	16	3	1	7	2.0	0.01
No. of D		4	2	5	5	5	5	5	4	5	5	5	5
BM-8M	20-May	< 0.05	0.030	3.81	0.16	0.2	0.06	196	1	2	100	4.9	0.05
	18-Jun	0.10	< 0.010	2.20	0.11	0.6	0.04	190	3	2	100	5.6	0.04
	22-Jul	0.15	< 0.010	2.25	0.04	1.0	0.01	155	12	3	84	6.2	0.01
	19-Aug	0.18	10.080	1.30	0.11	1.3	0.03	178	13	5	86	9.2	0.04
	01-Oct	0.22	< 0.010	1.02	0.09	1.4	0.05	180	3	3	104	7.0	0.03
Mean		0.14	2.028	2.12	0.10	0.9	0.04	180	6	3	95	6.6	0.03
Maximum		0.22	10.080	3.81	0.16	1.4	0.06	196	13	5	104	9.2	0.05
Minimum		0.05	0.010	1.02	0.04	0.2	0.01	155	1	2	84	4.9	0.01
Std. Dev		0.07	4.501	1.09	0.04	0.5	0.02	16	6	1	9	1.6	0.02
No. of D		4	2	5	5	5	5	5	5	5	5	5	5
BM-8B	20-May	< 0.05	0.024	3.53	0.17	0.4	0.07	204	20	2	81	4.2	0.06
	18-Jun	0.26	1.100	2.10	0.23	0.8	0.09	197	10	3	112	2.9	0.07
	22-Jul	1.35	< 0.010	0.98	0.24	1.5	0.1	211	23	4	138	4.5	0.08
	19-Aug	0.67	< 0.010	1.28	0.26	2.2	0.07	219	11	3	108	5.8	0.08
	01-Oct	0.27	< 0.010	1.04	0.13	1.3	0.05	186	21	3	98	13.7	0.04
Mean		0.52	0.231	1.79	0.21	1.2	0.08	203	17	3	107	6.2	0.07
Maximum		1.35	1.100	3.53	0.26	2.2	0.10	219	23	4	138	13.7	0.08
Minimum		0.05	0.010	0.98	0.13	0.4	0.05	186	10	2	81	2.9	0.04
Std. Dev		0.52	0.486	1.07	0.05	0.7	0.02	13	6	1	21	4.3	0.02
No. of D		4	2	5	5	5	5	5	5	5	5	5	5

Table 3-2. (Continued)

STATION	DATE	NH3	NO2	NO3	PO4	TKN	TP	TDS	TSS	BOD5	ALK	CHL_A	DISS_P
BM-9S	20-May	< 0.05	0.020	4.14	0.11	0.2	0.04	212	4	2	100	4.7	0.04
	18-Jun	0.11	1.100	2.50	0.11	0.7	0.04	193	4	< 2	108	5.4	0.04
	22-Jul	0.13	< 0.010	2.16	0.02	1.1	0.01	157	1	3	88	7.7	0.01
	19-Aug	0.18	< 0.010	1.55	0.08	2.0	0.02	180	7	6	84	7.6	0.02
	01-Oct	0.30	< 0.010	0.97	0.07	1.3	0.03	173	2	2	100	3.3	0.02
Mean		0.15	0.230	2.26	0.08	1.1	0.03	183	4	3	96	5.8	0.03
Maximum		0.30	1.100	4.14	0.11	2.0	0.04	212	7	6	108	7.7	0.04
Minimum		0.05	0.010	0.97	0.02	0.2	0.01	157	1	2	84	3.3	0.01
Std. Dev		0.09	0.486	1.20	0.04	0.7	0.01	21	2	2	10	1.9	0.01
No. of D		4	2	5	5	5	5	5	5	4	5	5	5
BM-9M	20-May	< 0.05	0.028	3.95	0.11	0.1	0.04	218	5	3	98		0.04
	18-Jun	0.23	0.600	2.70	0.12	1.0	0.04	240	4	3	130	3.8	0.04
	22-Jul	0.26	< 0.010	1.74	0.03	1.5	0.02	177	8	2	94	6.4	0.01
	19-Aug	0.41	< 0.010	1.85	0.11	1.4	0.04	193	2	2	104	3.7	0.03
	01-Oct	0.31	< 0.010	1.06	0.13	1.4	0.06	171	5	2	100	3.3	0.04
Mean		0.25	0.132	2.26	0.10	1.1	0.04	200	5	2	105	4.3	0.03
Maximum		0.41	0.600	3.95	0.13	1.5	0.06	240	8	3	130	6.4	0.04
Minimum		0.05	0.010	1.06	0.03	0.1	0.02	171	2	2	94	3.3	0.01
Std. Dev		0.13	0.262	1.11	0.04	0.6	0.01	29	2	1	14	1.4	0.01
No. of D		4	2	5	5	5	5	5	5	5	5	4	5
BM-9B	20-May	0.10	0.042	4.45	0.50	< 0.1	0.17	164	37	2	100	6.8	0.16
	18-Jun	0.47	1.000	2.10	0.18	1.5	0.06	212	12	4	116	1.9	0.06
	22-Jul	1.78	< 0.010	0.86	0.22	1.8	0.19	246	7	3	146	1.9	0.07
	19-Aug	2.45	< 0.010	0.43	0.22	4.7	0.23	244	20	2	184	3.8	0.07
	01-Oct	0.33	< 0.010	2.31	0.23	1.1	0.09	208	37	3	120	2.8	0.08
Mean		1.03	0.214	2.03	0.27	1.8	0.15	215	23	3	133	3.4	0.09
Maximum		2.45	1.000	4.45	0.50	4.7	0.23	246	37	4	184	6.8	0.16
Minimum		0.10	0.010	0.43	0.18	0.1	0.06	164	7	2	100	1.9	0.06
Std. Dev		1.03	0.439	1.57	0.13	1.7	0.07	33	14	1	33	2.0	0.04
No. of D		5	2	5	5	4	5	5	5	5	5	5	5
BM-10S	20-May	< 0.05	0.032	5.26	0.20	0.2	0.07	160	6	< 2	112	6.1	0.06
	18-Jun	0.11	1.100	2.80	0.14	1.3	0.05	209	8	3	116	10.6	0.05
	22-Jul	0.12	< 0.010	2.17	0.11	1.4	0.03	162	10	4	70	10.6	0.04
	19-Aug	0.17	< 0.010	1.25	0.17	2.1	0.01	157	7	6	78	10.8	0.05
	01-Oct	0.25	< 0.010	1.11	0.17	1.5	0.07	177	3	3	102	7.7	0.06
Mean		0.14	0.232	2.52	0.16	1.3	0.05	173	7	4	96	9.1	0.05
Maximum		0.25	1.100	5.26	0.20	2.1	0.07	209	10	6	116	10.8	0.06
Minimum		0.05	0.010	1.11	0.11	0.2	0.01	157	3	2	70	6.1	0.04
Std. Dev		0.07	0.485	1.68	0.03	0.7	0.03	22	3	2	21	2.1	0.01
No. of D		4	2	5	5	5	5	5	5	4	5	5	5

Table 3-2. (Continued)

STATION	DATE	NH3	NO2	NO3	PO4	TKN	TP	TDS	TSS	BOD5	ALK	CHL_A	DISS_P
BM-10M	20-May	< 0.05	0.031	5.30	0.14	0.3	0.07	182	9	< 2	112	8.4	0.05
	18-Jun	0.15	< 0.010	3.00	0.13	1.0	0.05	217	9	< 2	124	5.4	0.04
	22-Jul	0.13	< 0.010	2.04	0.12	1.1	0.04	160	10	3	74	12.5	0.04
	19-Aug	0.33	< 0.010	2.02	0.20	2.0	0.03	190	19	< 2	106	8.7	0.07
	01-Oct	0.22	< 0.010	1.10	0.22	1.3	0.07	177	< 1	4	102	5.8	0.07
Mean		0.18	0.014	2.69	0.16	1.1	0.05	185	10	3	104	8.2	0.05
Maximum		0.33	0.031	5.30	0.22	2.0	0.07	217	19	4	124	12.5	0.07
Minimum		0.05	0.010	1.10	0.12	0.3	0.03	160	1	2	74	5.4	0.04
Std. Dev		0.11	0.009	1.61	0.04	0.6	0.02	21	6	1	19	2.9	0.02
No. of D		4	1	5	5	5	5	5	4	2	5	5	5
BM-10B	20-May	< 0.05	0.035	5.13	0.26	0.3	0.12	166	24	2	98	3.6	0.08
	18-Jun	0.26	1.000	2.80	0.36	1.0	0.13	274	29	2	152	5.4	0.12
	22-Jul	1.22	< 0.010	1.81	0.14	1.9	0.05	259	17	2	164	6.5	0.05
	19-Aug	1.08	< 0.010	1.30	0.17	2.4	0.23	252	104	< 2	162	8.5	0.05
	01-Oct	0.21	< 0.010	2.94	0.68	0.9	0.3	225	145	3	138	2.9	0.22
Mean		0.56	0.213	2.80	0.32	1.3	0.17	235	64	2	143	5.4	0.10
Maximum		1.22	1.000	5.13	0.68	2.4	0.30	274	145	3	164	8.5	0.22
Minimum		0.05	0.010	1.30	0.14	0.3	0.05	166	17	2	98	2.9	0.05
Std. Dev		0.54	0.440	1.47	0.22	0.8	0.10	43	57	0	27	2.3	0.07
No. of D		4	2	5	5	5	5	5	5	4	5	5	5
BM-11S	20-May	< 0.05	0.175	1.52	0.43	0.6	0.23	182	10	< 2	102	2.4	0.14
	18-Jun	0.57	1.500	< 0.05	1.79	2.2	0.71	264	7	6	132	0.8	0.58
	22-Jul	0.18	< 0.010	0.93	0.11	1.2	0.07	146	7	< 2	82	2.1	0.04
	19-Aug	0.19	< 0.010	0.30	0.50	1.3	0.14	170	11	< 2	120	6.3	0.16
	01-Oct	0.14	< 0.010	1.95	0.14	0.7	0.05	161	8	< 2	80	16.8	0.05
Mean		0.23	0.341	0.95	0.59	1.2	0.24	185	9	3	103	5.7	0.19
Maximum		0.57	1.500	1.95	1.79	2.2	0.71	264	11	6	132	16.8	0.58
Minimum		0.05	0.010	0.05	0.11	0.6	0.05	146	7	2	80	0.8	0.04
Std. Dev		0.20	0.652	0.80	0.69	0.6	0.27	46	2	2	23	6.5	0.22
No. of D		4	2	4	5	5	5	5	5	1	5	5	5
BM-12S	20-May	0.10	0.017	3.78	0.05	0.3	0.03	92	9	2	28	2.9	0.02
	18-Jun	0.11	0.800	1.80	0.17	0.7	0.07	113	18	7	56	2.8	0.06
	22-Jul	0.16	< 0.010	0.93	0.13	0.6	0.12	147	15	< 2	82	5.8	0.04
	19-Aug	0.17	< 0.010	0.48	0.37	1.8	0.14	176	7	2	116	0.5	0.12
	01-Oct	0.13	< 0.010	2.04	0.10	0.8	0.04	156	7	< 2	74	2.6	0.03
Mean		0.13	0.169	1.81	0.16	0.8	0.08	137	11	3	71	2.9	0.05
Maximum		0.17	0.800	3.78	0.37	1.8	0.14	176	18	7	116	5.8	0.12
Minimum		0.10	0.010	0.48	0.05	0.3	0.03	92	7	2	28	0.5	0.02
Std. Dev		0.03	0.353	1.27	0.12	0.6	0.05	34	5	2	33	1.9	0.04
No. of D		5	2	5	5	5	5	5	5	3	5	5	5

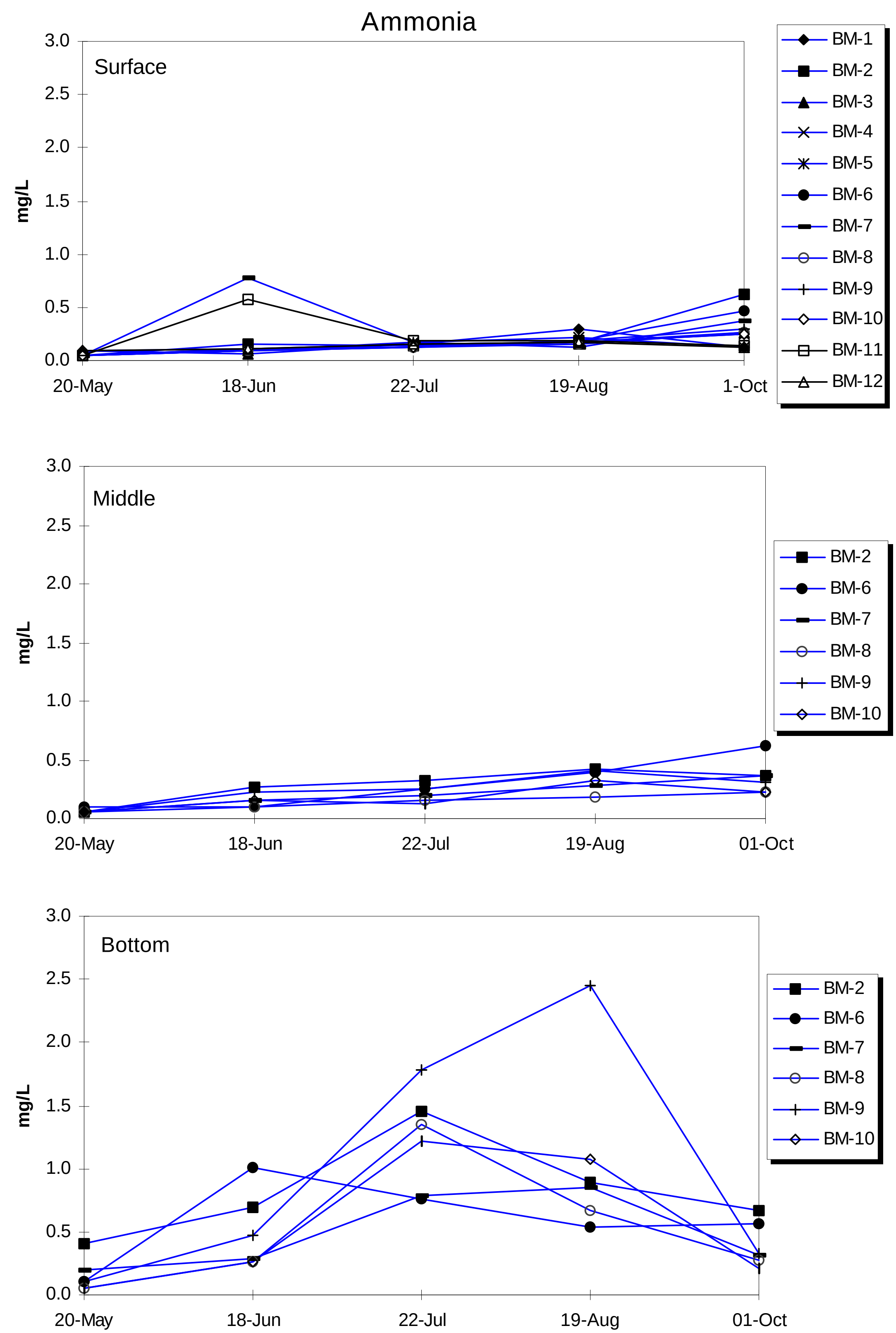

Figure 3-11. Ammonia measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

Table 3-3. PADEP ammonia nitrogen criteria (Pennsylvania Code, Title 25, Chapter 93, 1996). Specific ammonia criteria dependent on temperature and pH.

pH	10 °C	15 °C	20 °C	25 °C	30 °C
6.50	25.5	17.4	12.0	8.4	5.9
6.75	23.6	16.0	11.1	7.7	5.5
7.00	20.6	14.0	9.7	6.8	4.8
7.25	16.7	11.4	7.8	5.5	3.9
7.50	12.4	8.5	5.9	4.1	2.9
7.75	8.5	5.8	4.0	2.8	2.0
8.00	5.5	5.8	4.0	2.8	2.0
8.25	3.4	2.3	1.6	1.2	0.9
8.50	2.0	1.4	1.0	0.7	0.6
8.75	1.2	0.9	0.6	0.5	0.4
9.00	0.8	0.5	0.4	0.3	0.3
9.25	0.36	0.24	0.17	0.12	0.08
9.50	0.20	0.13	0.10	0.07	0.05

Table 3-4. Seasonal trends of ammonia at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant (at least $P < 0.05$).

Station	# of Years	Spring		Summer	
		P Level	Rate (mg/L/year)	P Level	Rate (mg/L/year)
Surface Water					
BM-1	21	NS	-0.0014	<0.01	-0.0194
BM-3	22	NS	-0.0056	< 0.01	-0.0169
BM-4	22	NS	-0.0006	NS	-0.0012
BM-5	21	NS	-0.0019	NS	-0.0046
BM-9	17	NS	-0.0007	NS	-0.0005
Surface and Bottom Water					
BM-2	18	<0.01	0.0196	NS	0.0203
BM-6	18	NS	0.0070	NS	0.0202

3.2.2 Nitrite and Nitrate

Nitrite concentrations were fairly uniform low throughout the water column of Blue Marsh Reservoir during 2002 (Fig. 3-12). Concentrations at most sampling locations and depths averaged 0.2 mg/L throughout the sampling period with the exception of BM-7 and BM-8 in August. The Nitrite concentration in the middle sampling point at BM-8 was 10.1 mg/L and at the bottom of BM-7 was 10.4 mg/L. These values were double checked

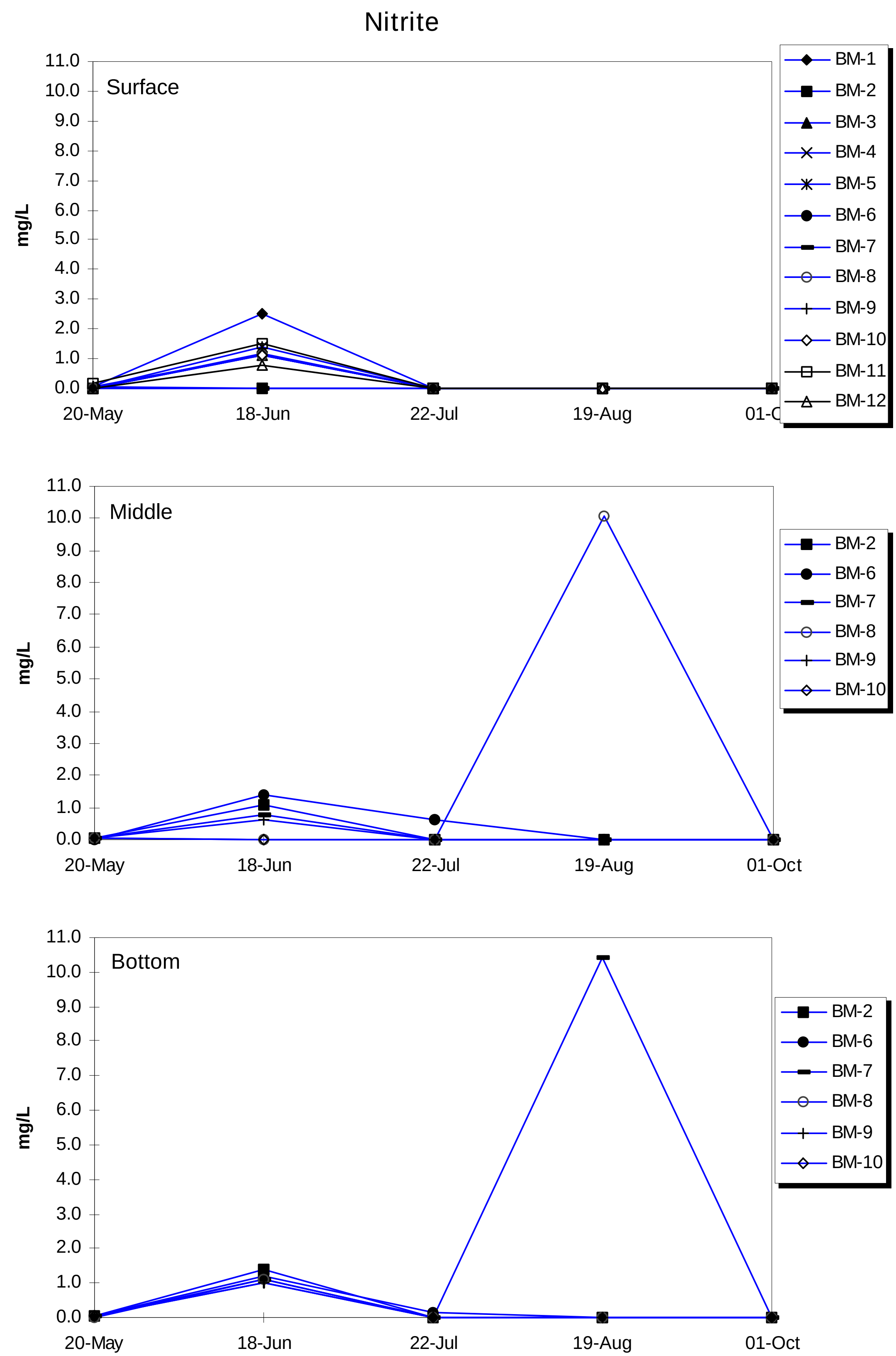

Figure 3-12. Nitrite measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

by the laboratory and confirmed to be correct. Additionally, values at both stations were less than the detection limit of 0.01 mg/L in October.

Nitrate concentrations were similar throughout the water column of Blue Marsh Reservoir and followed a decreasing pattern during 2002 from May through October (Fig. 3-13). Average concentrations at all sampling locations and depths averaged 3.93 mg/L during May and decreased to 1.44 mg/L in October. Consistently high nitrate concentrations were measured upstream on Tulpehocken Creek (station BM-5). Throughout the sampling period, concentrations at station BM-5 averaged 4.2 mg/L. The elevated concentrations were previously attributed to the proximity of the Bernville wastewater treatment facility located a short distance upstream; however, station BM-11 located just below the Bernville wastewater treatment facility and station BM-12, just above the treatment facility, were added to the sampling regime in 2002 and were also sampled again this year. Nitrate values at BM-11 averaged .95 mg/L throughout the sampling period and station BM-12 values averaged 1.81 mg/L. It appears that the increased nitrate concentrations at BM-5 are originating somewhere other than Northkill Creek where the treatment facility is located. Nitrate in the lower water column was similar and also less variable. In general, concentrations in the lower water column ranged from 0.14 to 5.3 mg/L over the monitoring period. The highest concentrations in bottom water were most often measured at station BM-10, where concentrations averaged of 2.8 mg/L.

Concentrations of nitrate and nitrite measured at Blue Marsh Reservoir were primarily in compliance with PADEP water quality standards during 2002, with the exception of BM-7 and BM-8 in August. The state water quality standard for nitrogen from nitrite and nitrate sources is a summed concentration of not more than 10 mg/L. Summed concentrations at most stations were two times less than the standard. The nitrogen concentration in the middle sampling point at BM-8 was 11.4 mg/L and 11.1 mg/L at the bottom of BM-7.

3.2.3 Total Inorganic Nitrogen

Total inorganic nitrogen, derived from ammonia, nitrite, and nitrate, in surface waters and downstream of Blue Marsh Reservoir has not changed appreciably over the past 20 years in either spring or summer seasons. Regression analyses on summed concentrations of ammonia, nitrite, and nitrate calculated separately for reservoir and upstream stations (BM-2, -3, -4, and -5) and downstream (BM-1) were not significant ($p > 0.05$) for either season (Figs. 3-14 and 3-15). In general, concentrations of total inorganic nitrogen at both locations have consistently averaged 3.8 mg/L in the spring and 2.2 mg/L in the summer. The 2002 seasonal averages for upstream reservoir and downstream locations were similar and consistent with the 20-year pattern. Estimated 2002 concentrations were approximately 4.2 mg/L in the spring and 3.3 mg/L in the summer.

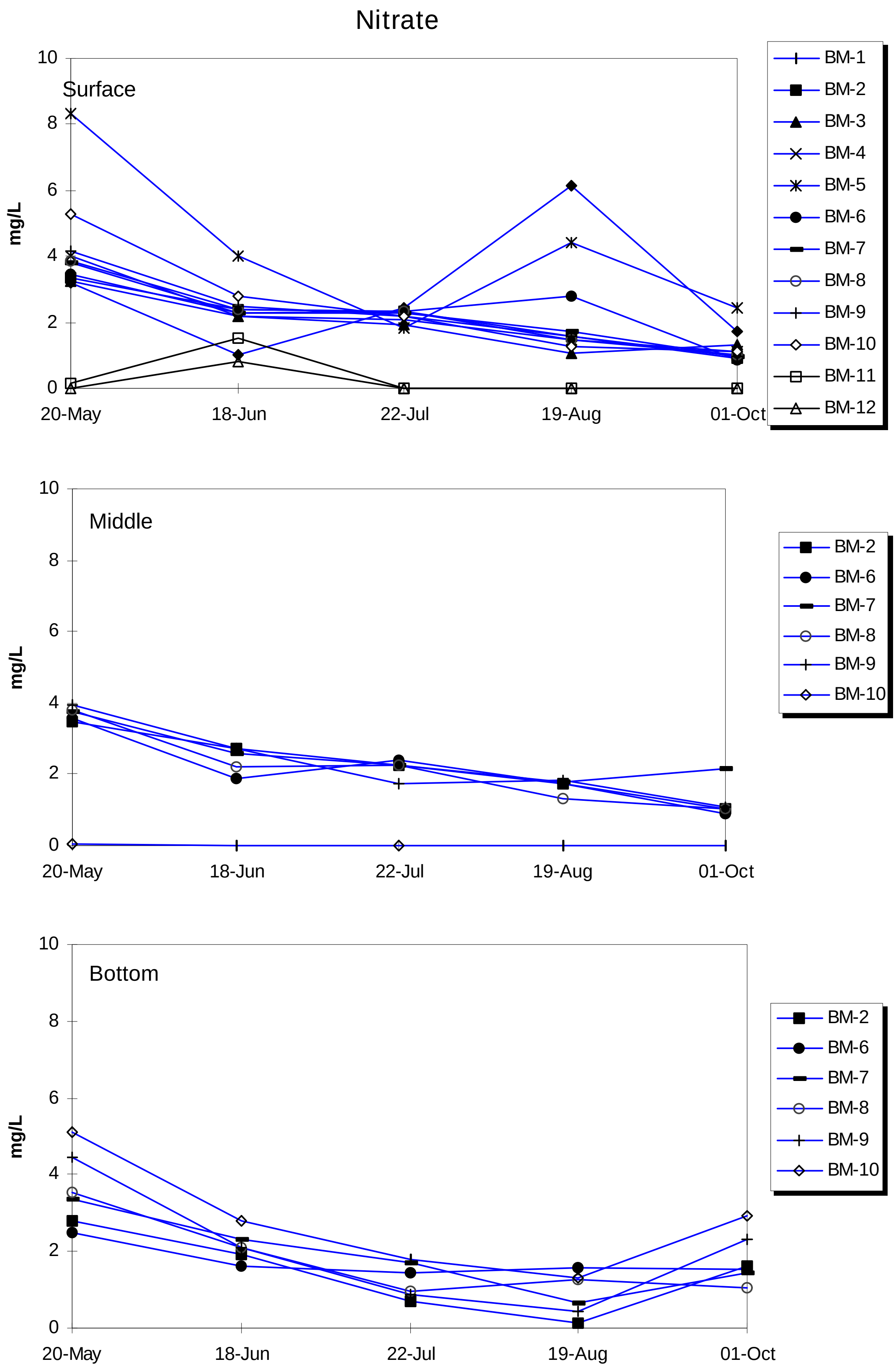

Figure 3-13. Nitrate measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

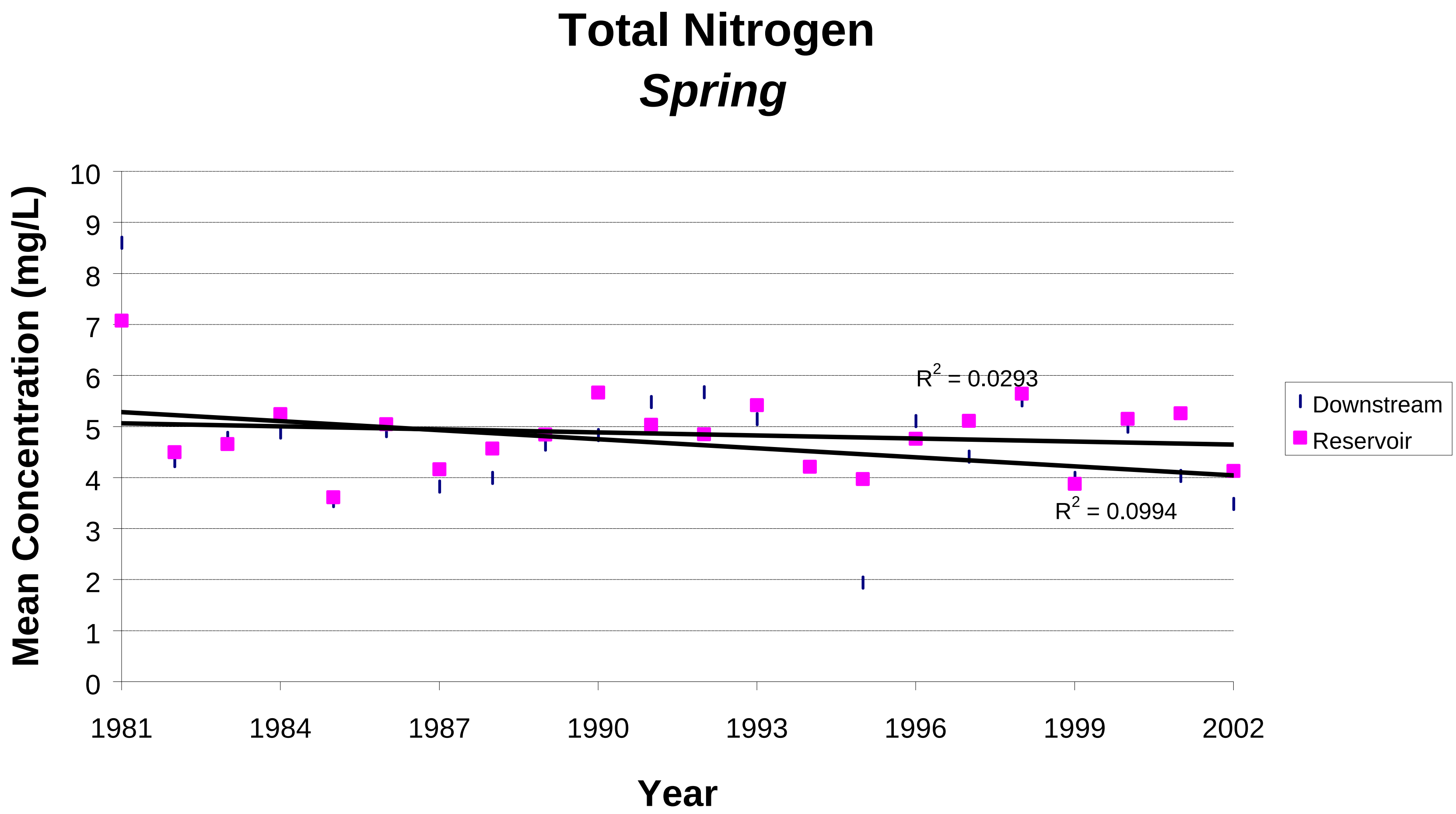

Figure 3-14. Seasonal trends in total nitrogen (ammonia + nitrite + nitrate) in the spring at Blue Marsh Reservoir

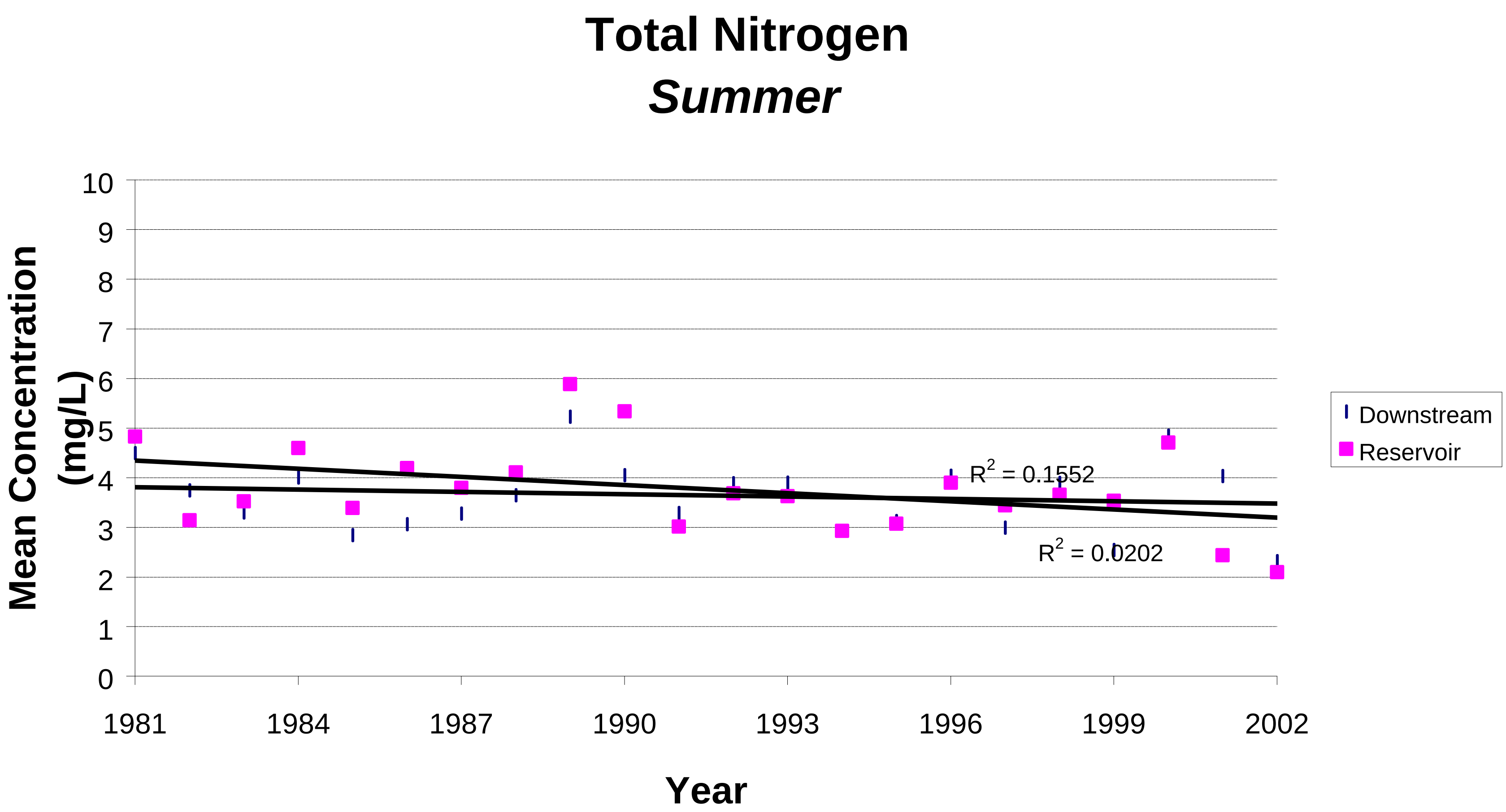

Figure 3-15. Seasonal trends in total nitrogen (ammonia + nitrite + nitrate) in the summer at Blue Marsh Reservoir

Although total inorganic nitrogen may not be changing in the reservoir viewed in it's entirety, trend analyses for individual monitoring stations suggest that decreases have occurred at upstream sources in the spring and summer on Licking Creek (BM-4). Additionally, Spring Creek (BM-3) Creek showed a significant decreasing trend during the summer (Table 3-5).

Table 3-5. Seasonal trends of total inorganic nitrogen at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant (at least $P < 0.05$).

Station	# of Years	Spring		Summer	
		P Level	Rate (mg/L/year)	P Level	Rate (mg/L/year)
Surface Water					
BM-1	21	NS	-0.0201	NS	-0.0190
BM-3	22	NS	-0.0063	< 0.001	-0.1097
BM-4	22	< 0.05	-0.0638	< 0.001	-0.0987
BM-5	21	NS	0.1013	NS	0.0637
BM-9	17	NS	0.0070	NS	-0.0399
Surface and Bottom Water					
BM-2	18	NS	0.0083	NS	-0.0466
BM-6	18	NS	-0.0002	NS	-0.0070

Significant decreasing trends were determined for stations BM-3 and BM-4. BM-3 was significant only in the summer, whereas BM-4 was significant in the spring and summer seasons. The rates of decrease estimated for both stations in the summer were similar and averaged 0.1 mg/L/year (Table 3-5). The reduction of total inorganic nitrogen at these upstream sources can be considered as an improvement in the overall water quality of Blue Marsh Reservoir.

3.2.4 Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen that is inclusive of ammonia. In general, TKN remained low but variable throughout the water column of Blue Marsh Reservoir (Fig. 3-16). Concentrations measured in all surface and middle waters including downstream of the reservoir averaged 1.1 mg/L. Concentrations measured near the bottom were higher, averaging 1.5 mg/L and ranged as high as 4.7 mg/L at station BM-9 during August.

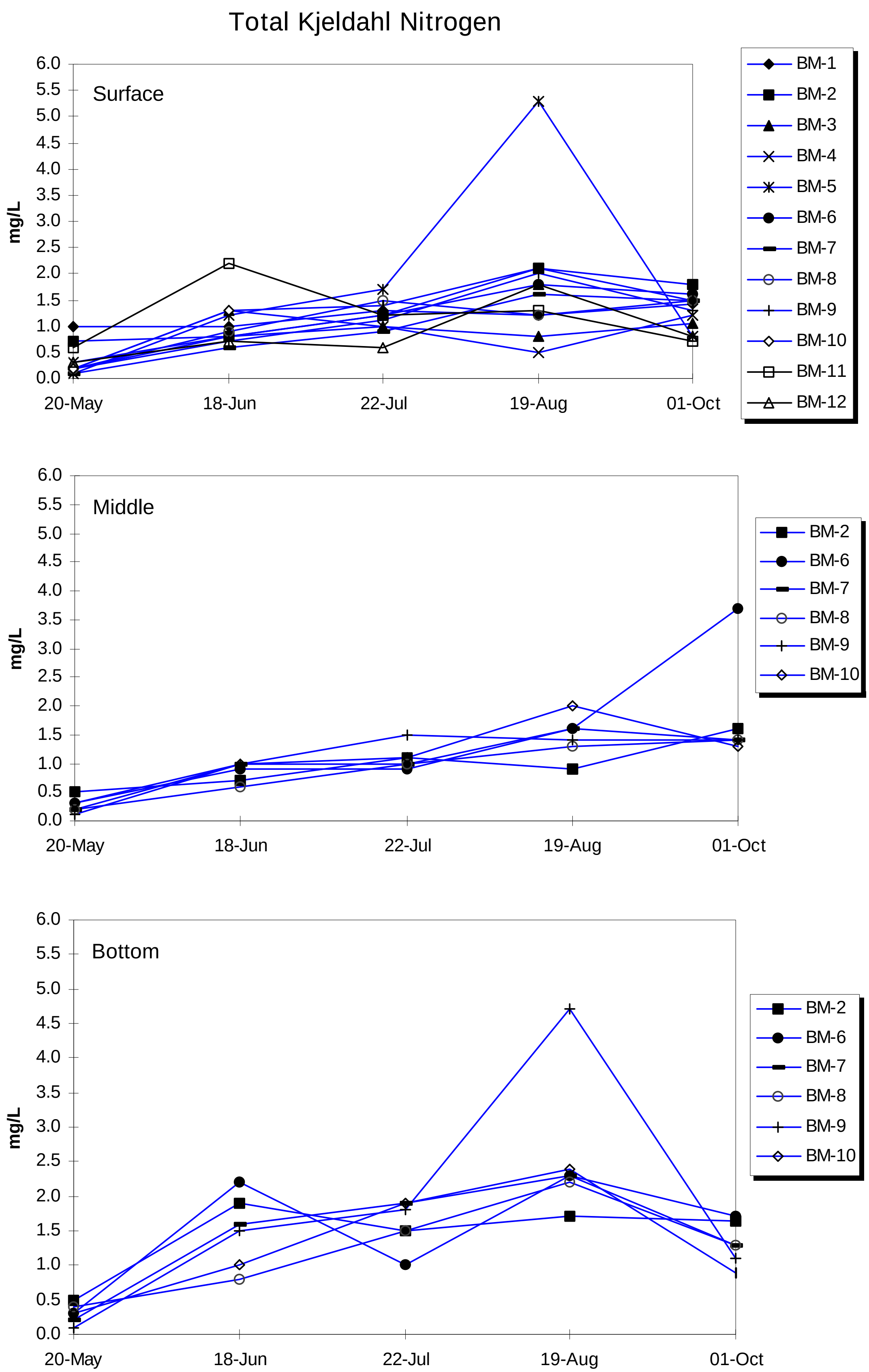

Figure 3-16. Total Kjeldahl nitrogen measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

3.2.5 Dissolved Phosphate

Dissolved phosphate in the water column of Blue Marsh Reservoir was consistently low during 2002. Concentrations measured at all stations and most depths average 0.17-mg/L throughout the monitoring period (Fig. 3-17). The highest concentration of dissolved phosphate (1.79-mg/L) was measured upstream of the reservoir at BM-11 in June.

3.2.6 Total Dissolved Phosphorus

Total dissolved phosphorus in the water column of Blue Marsh Reservoir was consistently low during 2002. Concentrations measured at all stations and most depths average 0.055-mg/L throughout the monitoring period (Fig. 3-18). The highest concentration of total dissolved phosphorus (0.6-mg/L) was measured upstream of the reservoir at BM-11 in June.

3.2.7 Total Phosphorus

Total phosphorus in the water column of Blue Marsh Reservoir was frequently measured at high concentrations during 2002 (Fig. 3-19). EPA guidance for nutrient criteria in lakes and reservoirs suggests a minimum concentration for total phosphorus of 0.01-mg/L (EPA 2000). Lakes and reservoirs exceeding this concentration are more likely to experience algal bloom problems during the growing season. Overall, 95% of the measures for total phosphorus with results greater than the detection limit from reservoir monitoring were greater than the EPA guideline. The remaining 5 results were less than a detection limit of 0.01-mg/L, which is equal to the guideline.

Concentrations of total phosphorus were fairly uniform throughout the reservoir and less than 0.35-mg/L (Fig. 3-19). An anomalously high concentration of 0.71-mg/L resulted at BM-11 at the surface in June; however, the average throughout the reservoir was 0.1 mg/L.

Total phosphorus concentrations measured during 2002 and historical data from the past 20 years were analyzed for seasonal trends at Blue Marsh Reservoir. Spring and summer trend analyses were conducted separately for stations representing the reservoir and downstream. The regression analyses indicated that total phosphorus concentrations within Blue Marsh Reservoir have declined over spring and summer seasons (Figs. 3-20 and 3-21). The spring reservoir trend was strong ($R^2 = 0.50$, $P < 0.0002$), and reflected an average 10-year decrease of 0.05 mg/L (Fig. 3-20). The summer reservoir trend was similarly strong ($R^2 = 0.43$, $P < 0.0009$), and reflected an average 10-year decrease of 0.07 mg/L (Fig. 3-21). The average concentrations calculated for 2002 were generally

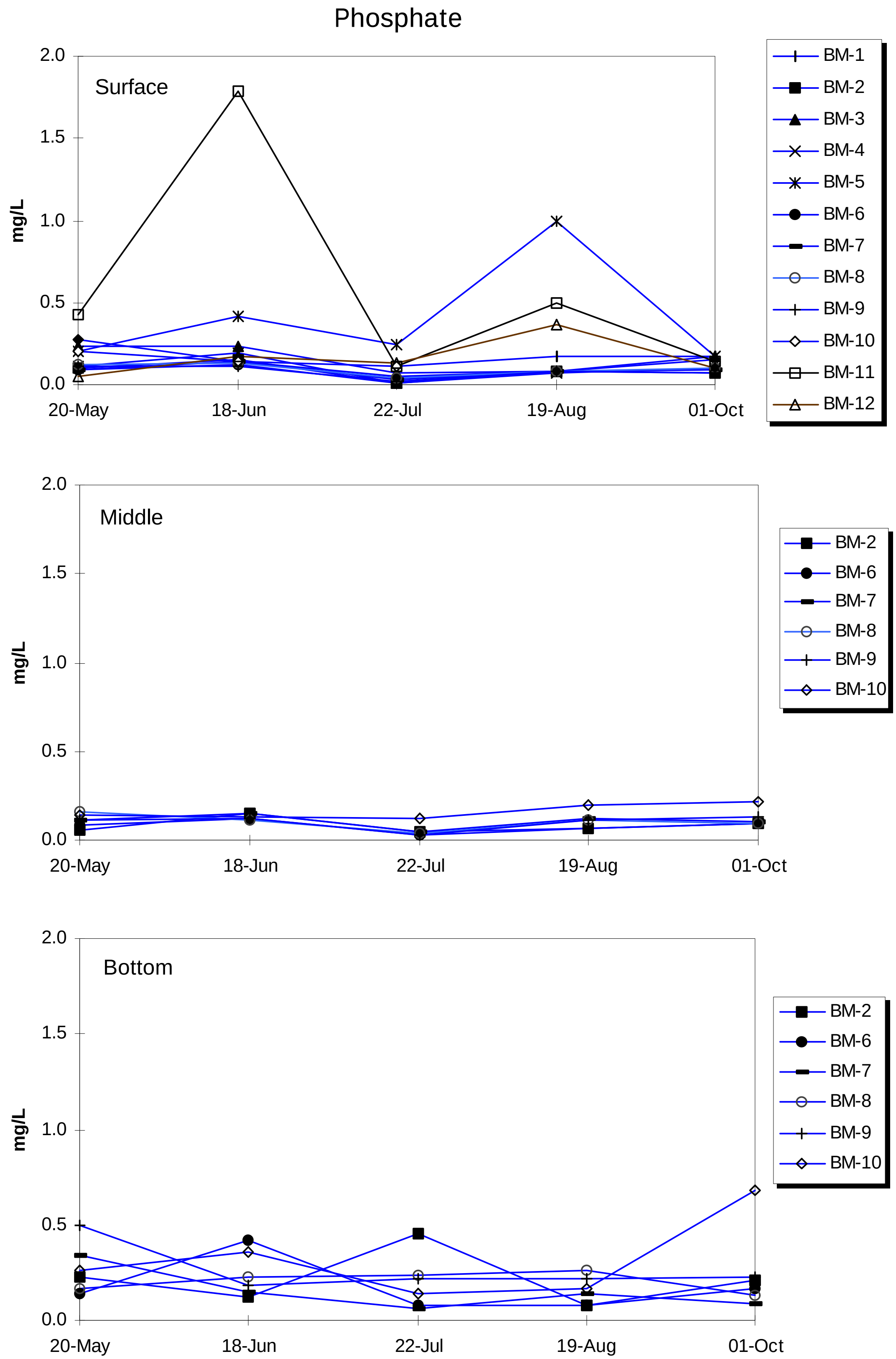

Figure 3-17. Phosphate measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

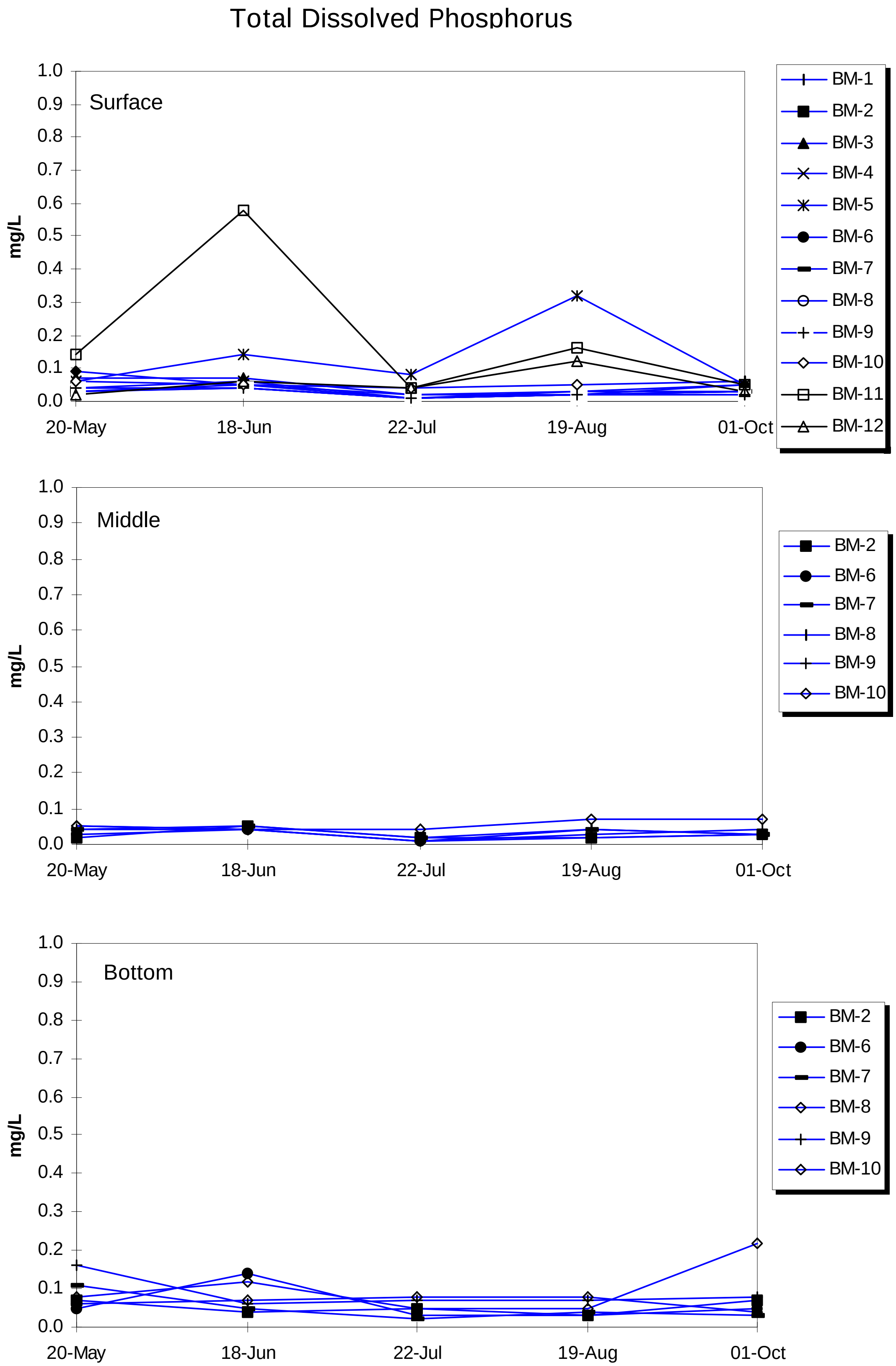

Figure 3-18. Total dissolved phosphorus measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

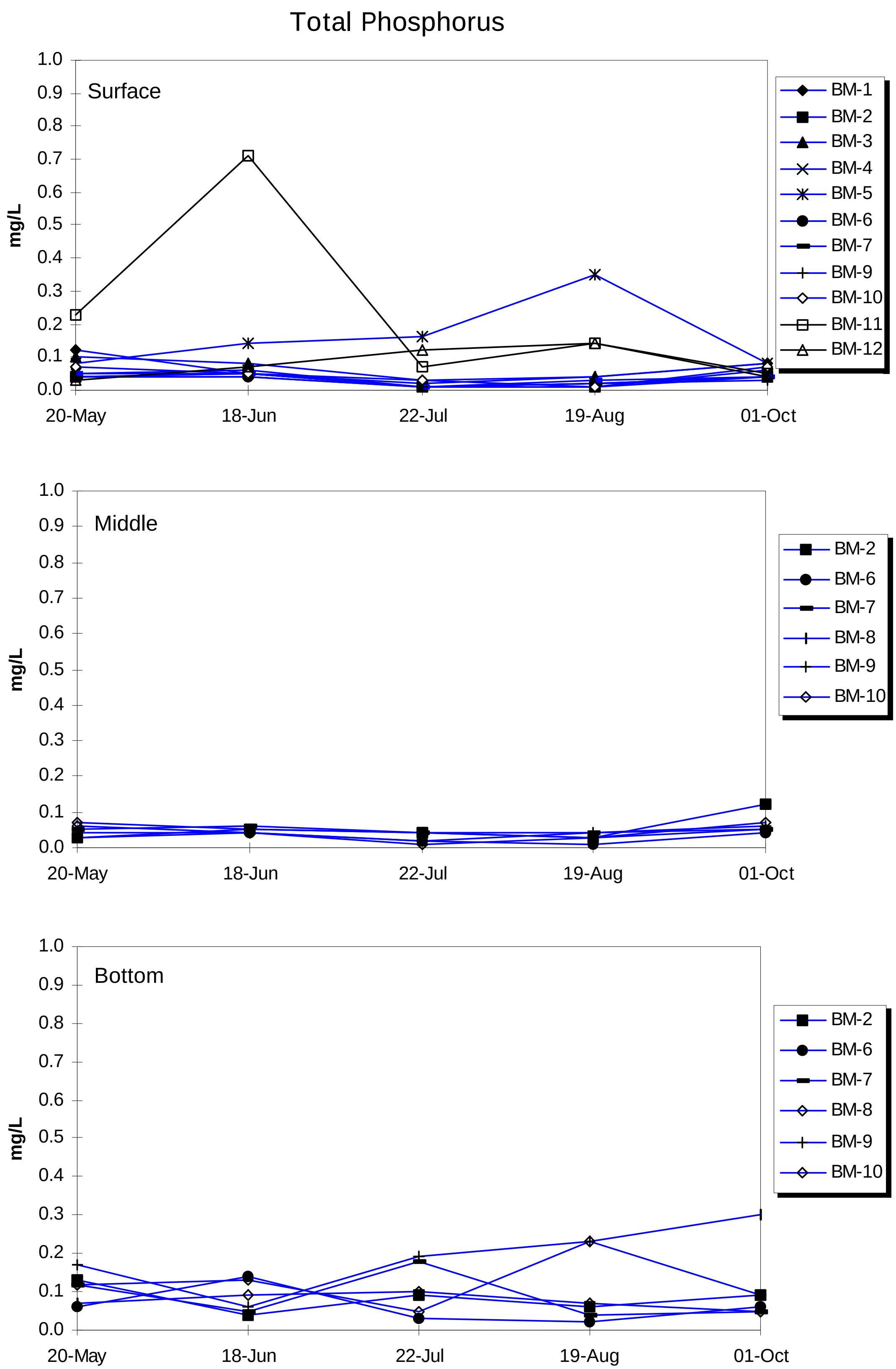

Figure 3-19. Total phosphorus measured in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

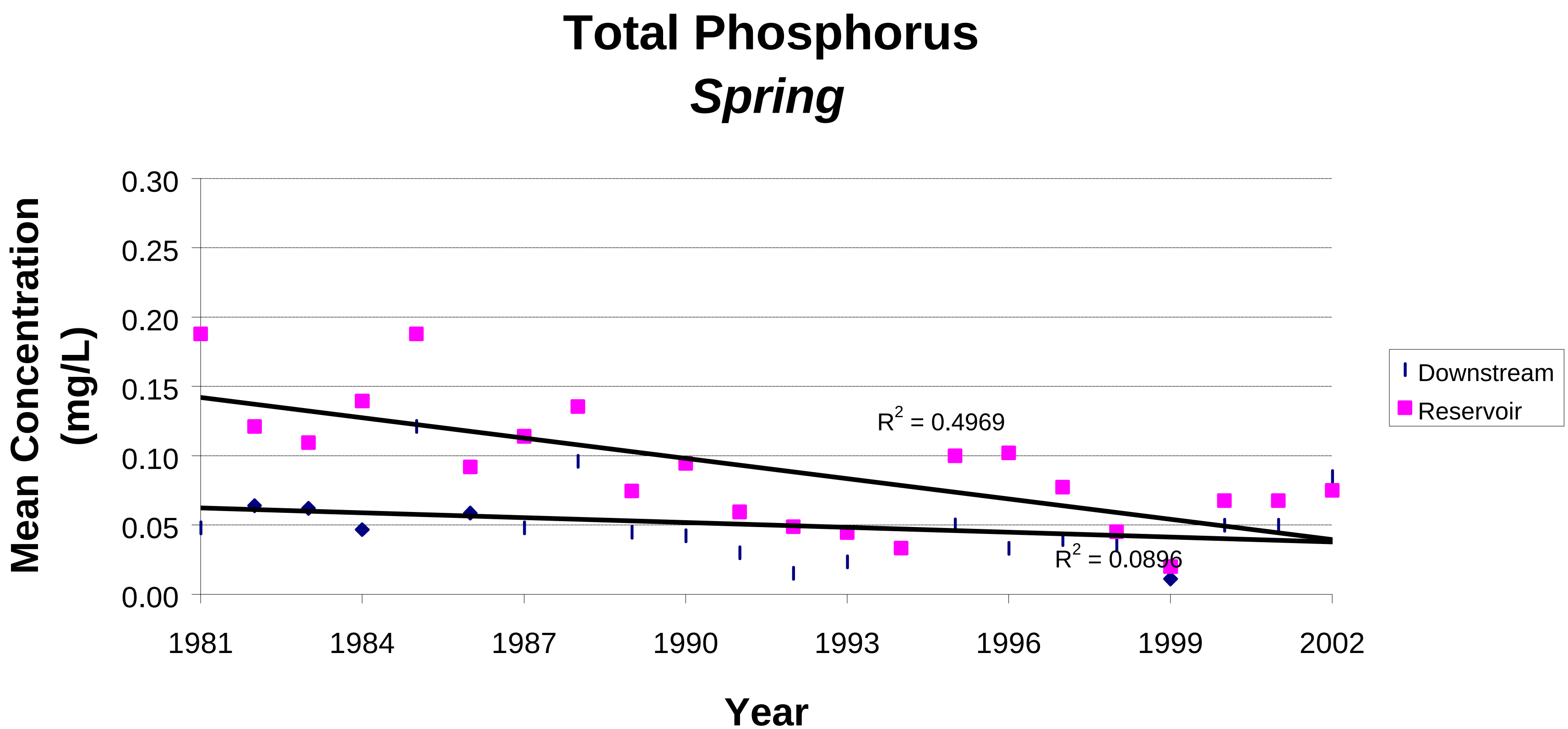

Figure 3-20. Seasonal trends in total phosphorus in spring at Blue Marsh Reservoir

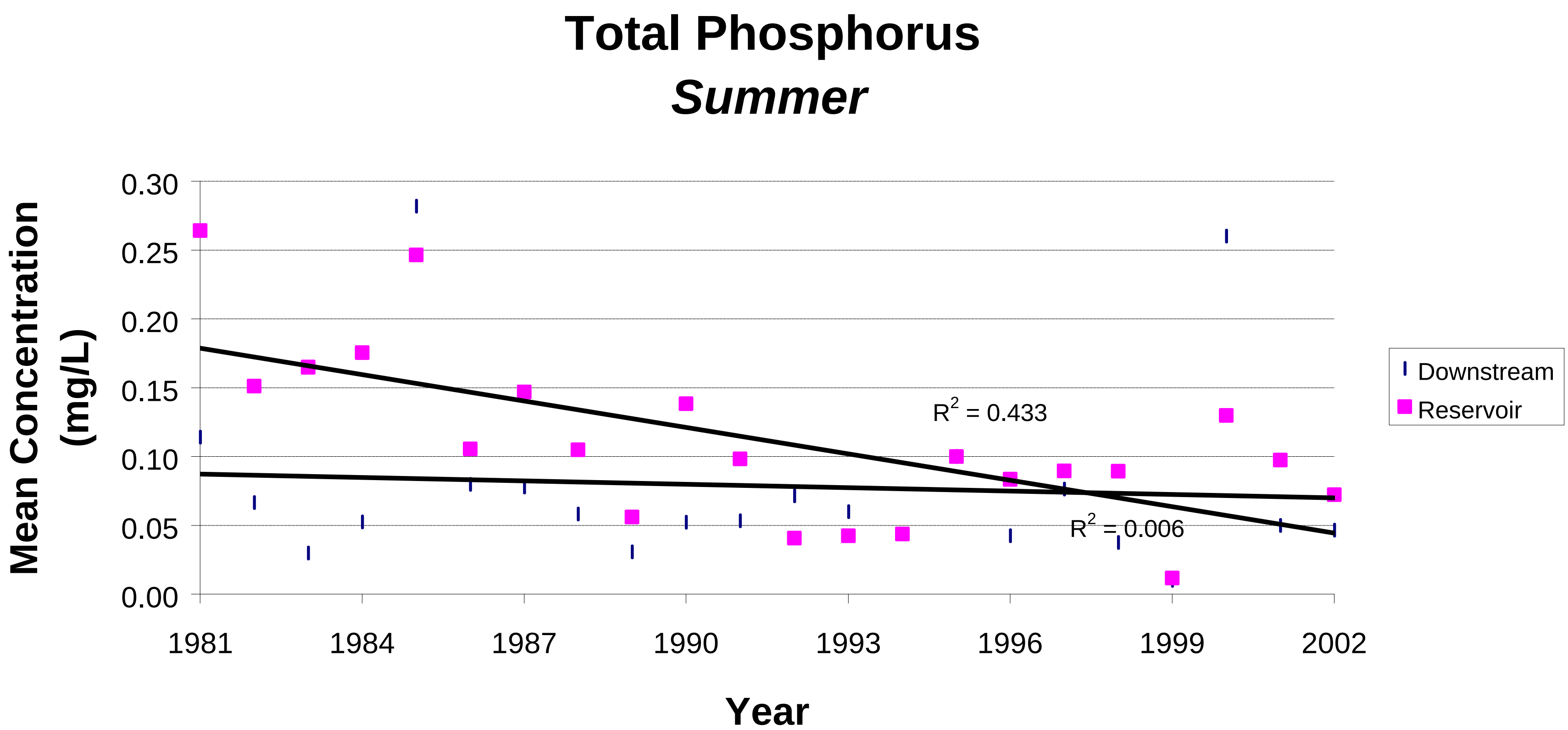

Figure 3-21. Seasonal trends in total phosphorus in summer at Blue Marsh Reservoir

above the regression line. Regardless, the historical data still indicate a decrease in the concentration of total phosphorus for Blue Marsh Reservoir over the past 20 years.

Trend analysis for total phosphorus was also conducted on individual monitoring stations of Blue Marsh Reservoir using the non-parametric Mann-Kendall Statistic. Significant decreasing trends for the spring season were determined for all surface water stations as well as BM-2. Significant decreasing trends were also determined for stations BM-1, -3, -4, and -9 during the summer (Table 3-6). The trends at station BM-3, located upstream on Spring Creek, are remarkable in their estimates of rates of decrease. The spring trend rate (-0.011 mg/L/year) is at least 3 times greater than rates of other spring trends. The summer trend rate (-0.018 mg/L/year) is even greater and could account for the decreases observed for the entire reservoir in the regression analysis.

Table 3-6. Seasonal trends of total phosphorus at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant (at least $P < 0.05$).

Station	# of Years	Spring		Summer	
		P Level	Rate (mg/L/year)	P Level	Rate (mg/L/year)
Surface Water					
BM-1	20	<0.05	-0.0016	<0.05	-0.0018
BM-3	21	<0.001	-0.0112	<0.001	-0.0184
BM-4	21	<0.01	-0.0034	<0.05	-0.0032
BM-5	20	<0.05	-0.0035	NS	-0.0035
BM-9	16	<0.05	-0.0030	<0.05	-0.0030
Surface and Bottom Water					
BM-2	17	<0.05	-0.0023	NS	-0.0006
BM-6	17	NS	-0.0010	NS	-0.0014

3.2.8 Total Dissolved Solids

Total dissolved solids (TDS) in the water column of Blue Marsh Reservoir were relatively consistent throughout the monitoring period (Fig. 3-22). Concentrations at most stations and depths averaged 189 mg/L on all monitoring dates. Among surface waters, station BM-5 usually had the highest concentrations at approximately 241-mg/L in most months. The elevated concentrations were previously attributed to the proximity of the Bernville wastewater treatment facility located a short distance upstream; however, station BM-11 located just below the Bernville wastewater treatment facility and station BM-12, just above the treatment facility, were also sampled this year. TDS concentrations at these stations averaged 160 mg/L throughout the sampling period. It appears that the

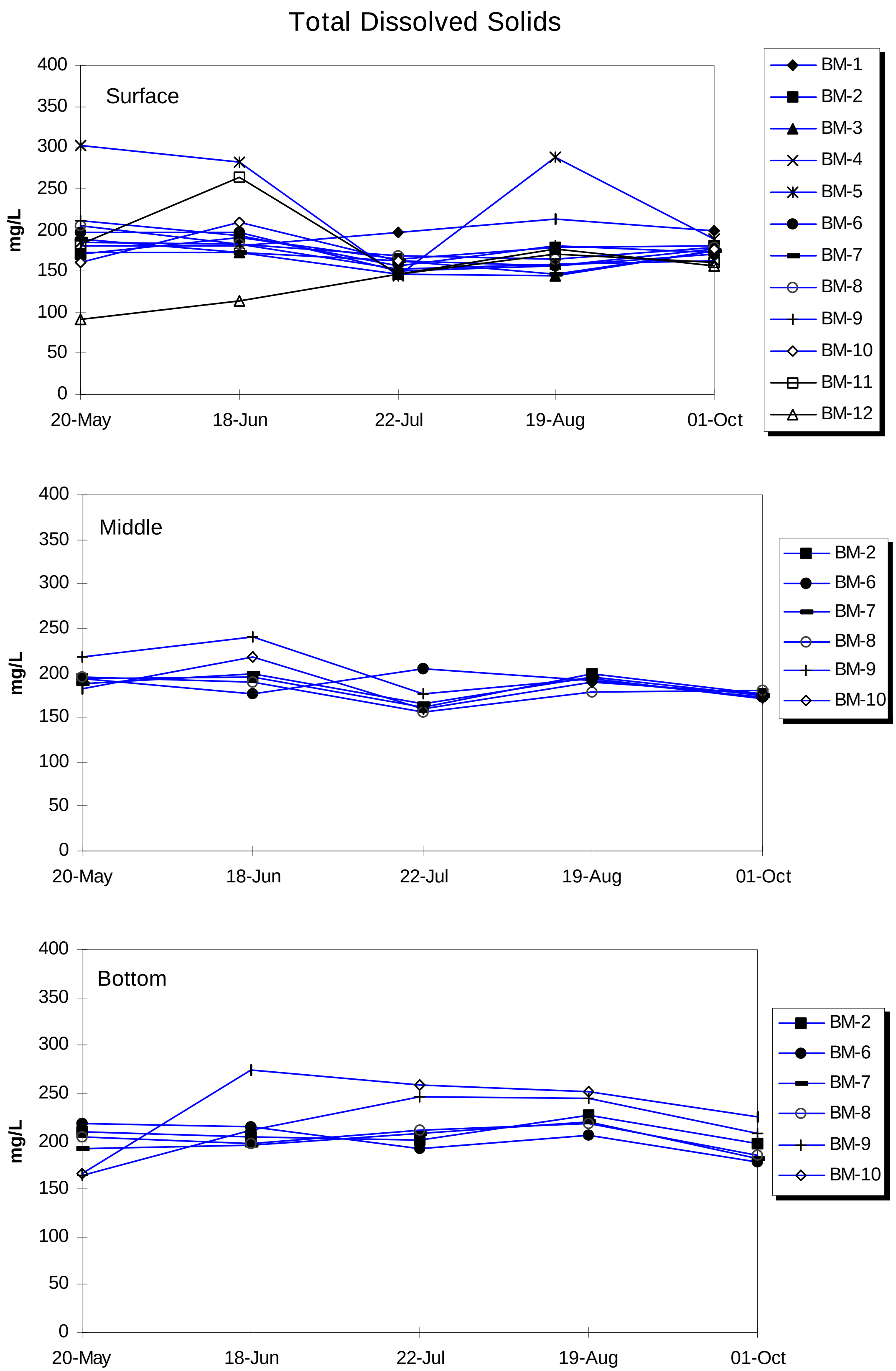

Figure 3-22. Total dissolved solids in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002. (The PADEP water quality standard for TDS is a maximum concentration of 500 mg/L.)

increased TDS concentrations at BM-5 are originating somewhere other than Northkill Creek where the treatment facility is located. TDS concentrations measured downstream (BM-1) were similar to other stations averaging 194 mg/L (Fig. 3-22).

Concentrations of total dissolved solids measured at Blue Marsh Reservoir were in compliance with PADEP water quality standards during 2002. The state water quality standard for TDS is a maximum concentration of 500 mg/L. All concentrations of TDS measured in surface, middle and bottom waters of the reservoir were at least 40% less than the standard.

Total dissolved solids concentrations have exhibited no discernible pattern over the past 20 years of water quality monitoring at Blue Marsh Reservoir. Regression analyses conducted separately by season for upstream and downstream data did not result in any significant trends (Figs. 3-23 and 3-24). Average TDS concentrations calculated this year were of the same order as in prior years.

Although TDS may not be changing in the reservoir viewed in it's entirety, trend analyses for individual monitoring stations suggest that decreases have occurred at upstream sources on Spring (BM-3) and Licking (BM-4) Creeks while an increase occurred in the lower reservoir in the spring season (station BM-2; Table 3-7). Seasonal trends (spring and summer) were determined for individual monitoring stations using the non-parametric Mann-Kendall Statistic. Significant decreasing trends were determined for both stations BM-3 and BM-4 in the summer. The rate of decrease at BM-3 was 5.26 mg/L/year and the rate of decrease at BM-4 was 1.56 mg/L/year. The reduction of TDS at these upstream sources suggests that an improvement in the overall water quality of Blue Marsh Reservoir occurred within the time series. The increasing trend for spring within the reservoir (station BM-2) was estimated to be increasing at a rate of 3.89 mg/L/year.

3.2.9 Total Suspended Solids

Total suspended solids (TSS) in the waters of Blue Marsh Reservoir were generally low during the 2002 sampling period (Fig. 3-25). Concentrations at most monitoring stations and all depths averaged 14-mg/L with few exceptions. Higher concentrations were measured in bottom water at stations BM-2, -6 and -10. Among these stations BM-6 peaked in June with a value of 196-mg/L.

The Pennsylvania Department of Environmental Protection (PADEP) has not issued a water quality standard for TSS.

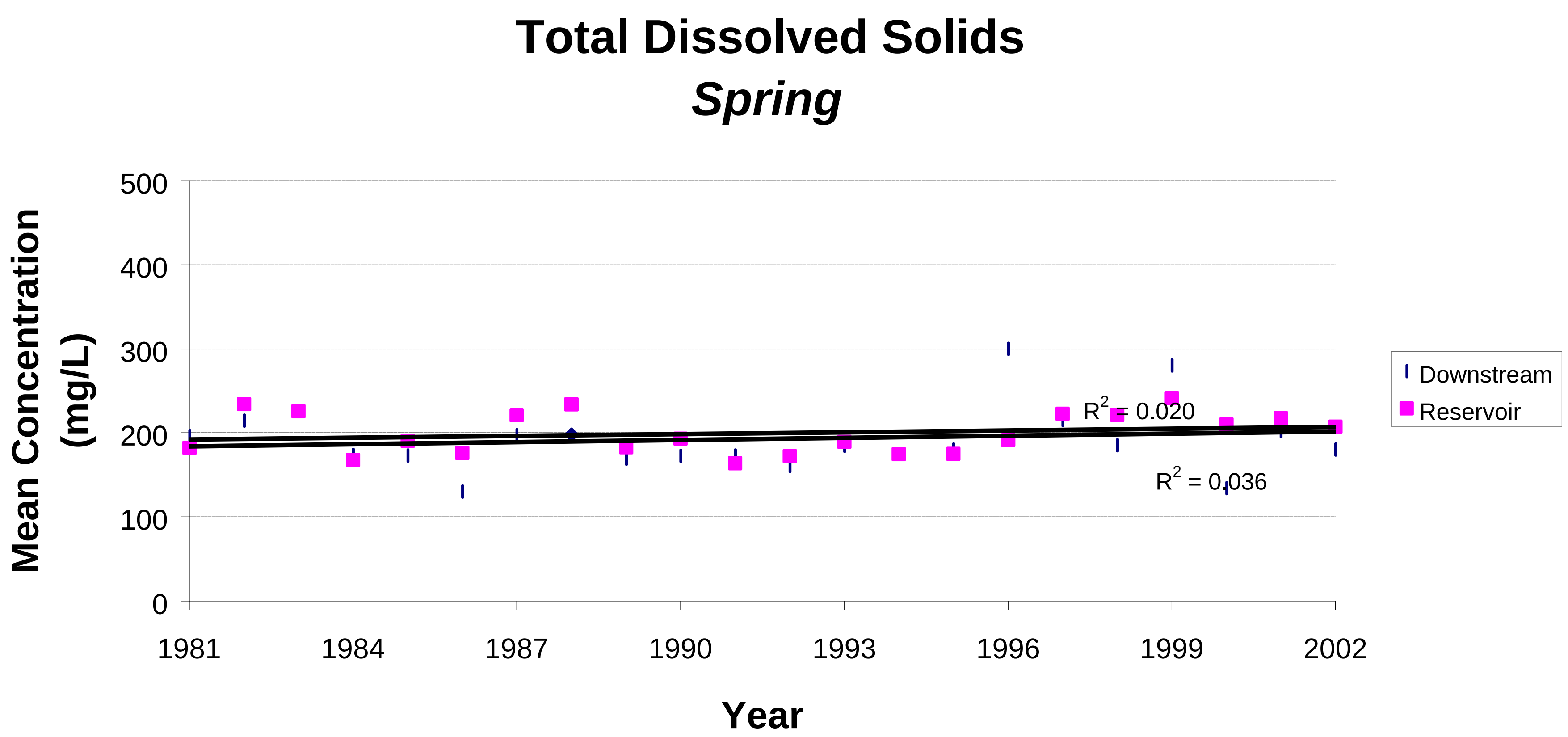

Figure 3-23. Seasonal trends for total dissolved solids in spring at Blue Marsh Reservoir

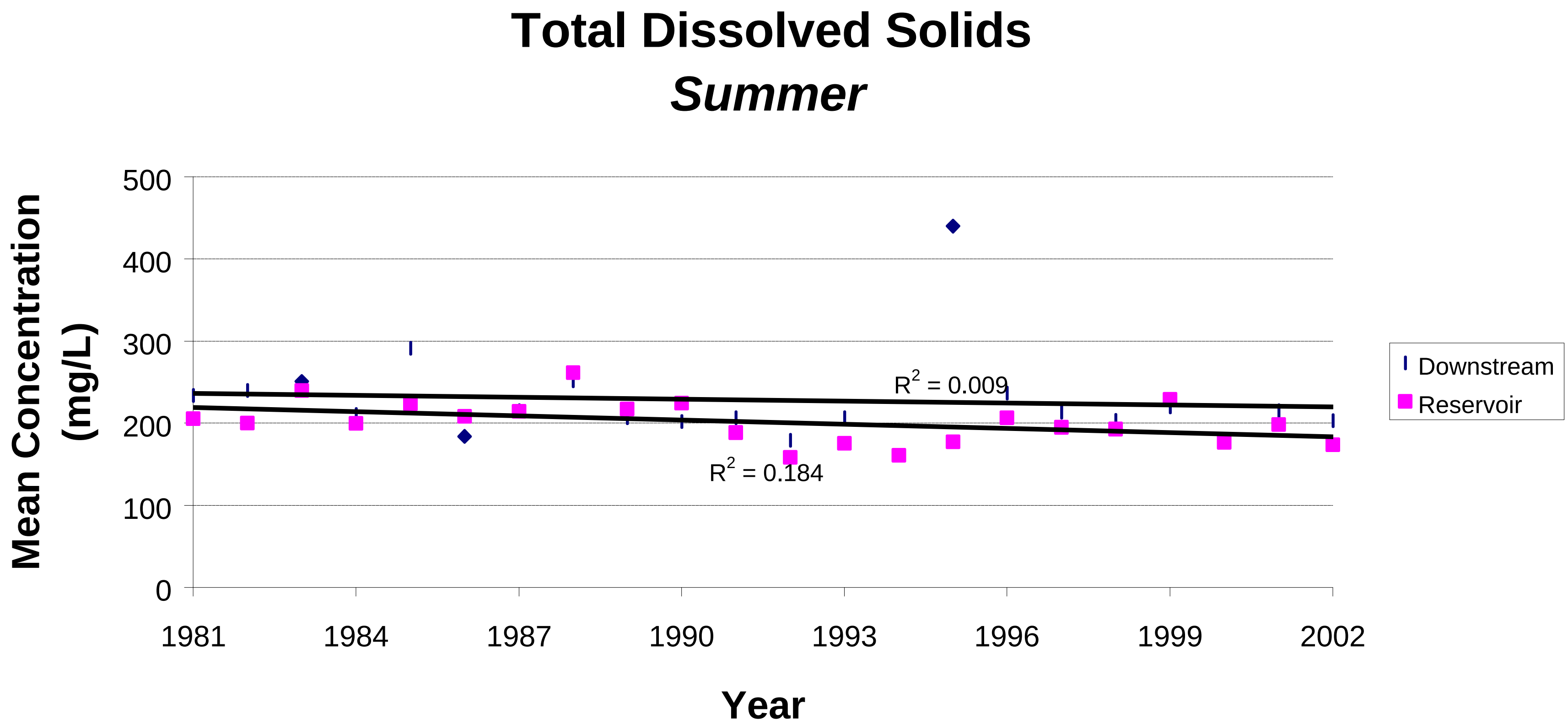

Figure 3-24. Seasonal trends for total dissolved solids in summer at Blue Marsh Reservoir

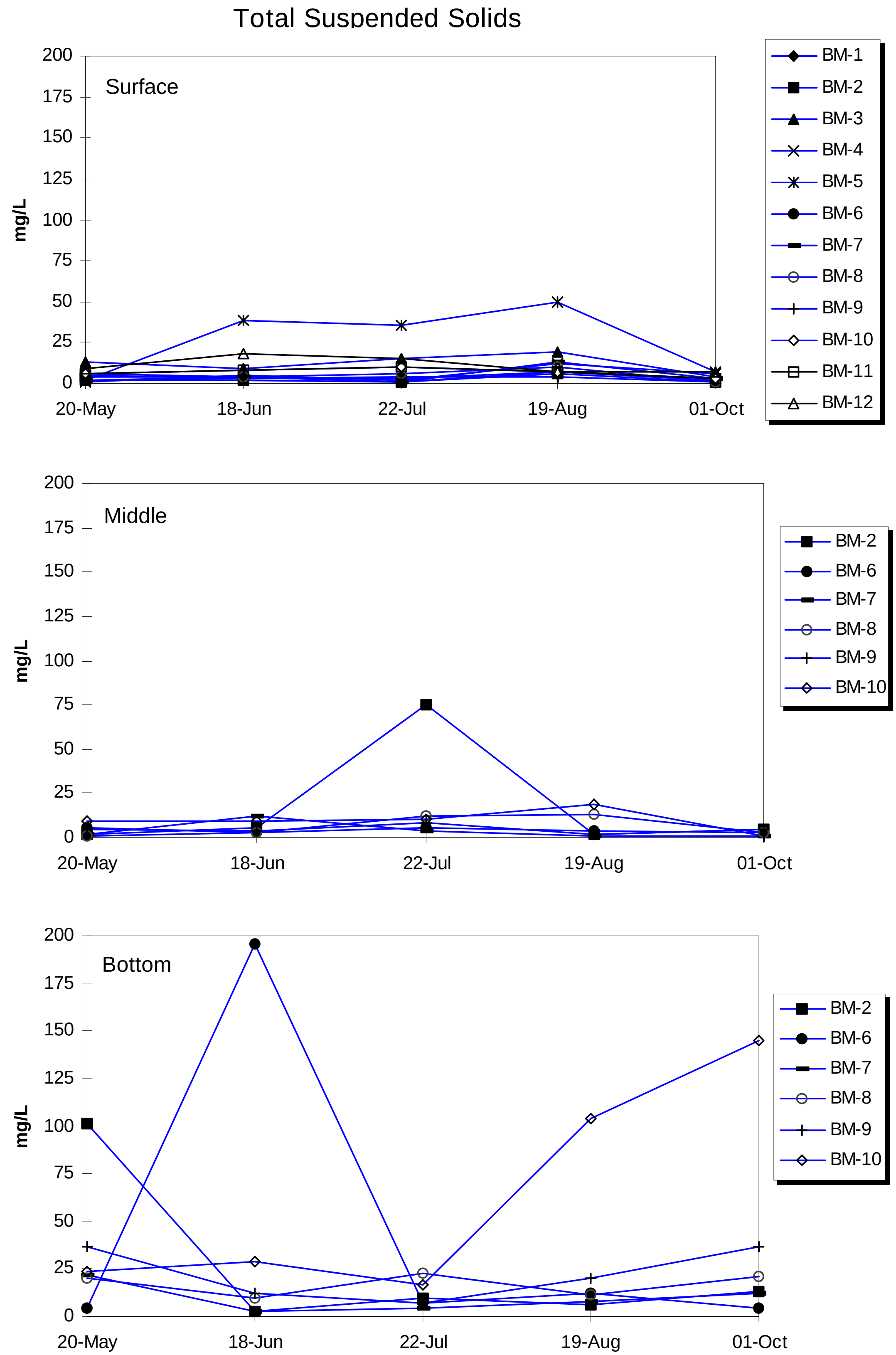

Figure 3-25. Total suspended solids in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

Table 3-7. Seasonal trends of total dissolved solids at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shade values are significant (at least P<0.05).

Station	# of Years	Spring		Summer	
		P Level	Rate (mg/L/year)	P Level	Rate (mg/L/year)
Surface Water					
BM-1	21	NS	0.2286	NS	-1.2104
BM-3	22	NS	-1.8750	< 0.01	-5.1095
BM-4	22	NS	0.5833	< 0.05	-1.5556
BM-5	21	NS	3.2841	NS	1.3537
BM-9	17	NS	0.1852	NS	-1.0722
Surface and Bottom Water					
BM-2	17	<0.05	3.8864	NS	0.2222
BM-6	17	NS	1.6667	NS	0.0667

3.2.10 Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of potential oxygen depletion imposed by organic material present in water. BOD in the water column of Blue Marsh Reservoir, for the most part, was relatively low during the 2002 sampling period (Fig. 3-26). The BOD at monitoring stations and all depths ranged from less than the method detection limits of 2-mg/L or less to 5 mg/L. Several higher values were detected at stations throughout the reservoir system but in no apparent pattern. Station BM-5 was highest among surface water stations in July at 10-mg/L, but averaged 2-mg/L in all other months. Station BM-6 was highest among the lower waters in June at 8-mg/L, but averaged 3-mg/L in all other months. BOD downstream of the reservoir (station BM-1) was consistently low throughout the monitoring period. All concentrations measured at station BM-1 were at or less than method detection limits (Fig. 3-26). The Pennsylvania Department of Environmental Protection (PADEP) does not issue a water quality standard for BOD.

Based on a trend analysis using 2002 and historical data, BOD did not appear to be decreasing in the Blue Marsh Reservoir system (Figs. 3-27 and 3-28). Regression lines were plotted for spring and summer seasons separately for the upstream reservoir (stations BM-2, BM-3, BM-4, and BM-5) and downstream (station BM-1) locations. No significant trends were apparent when this year's data were included in the analysis.

A trend analysis for BOD was also conducted on individual monitoring stations of Blue Marsh Reservoir using the non-parametric Mann-Kendall Statistic. Based on this analysis, no significant trends were apparent for individual reservoir stations (Table 3-8).

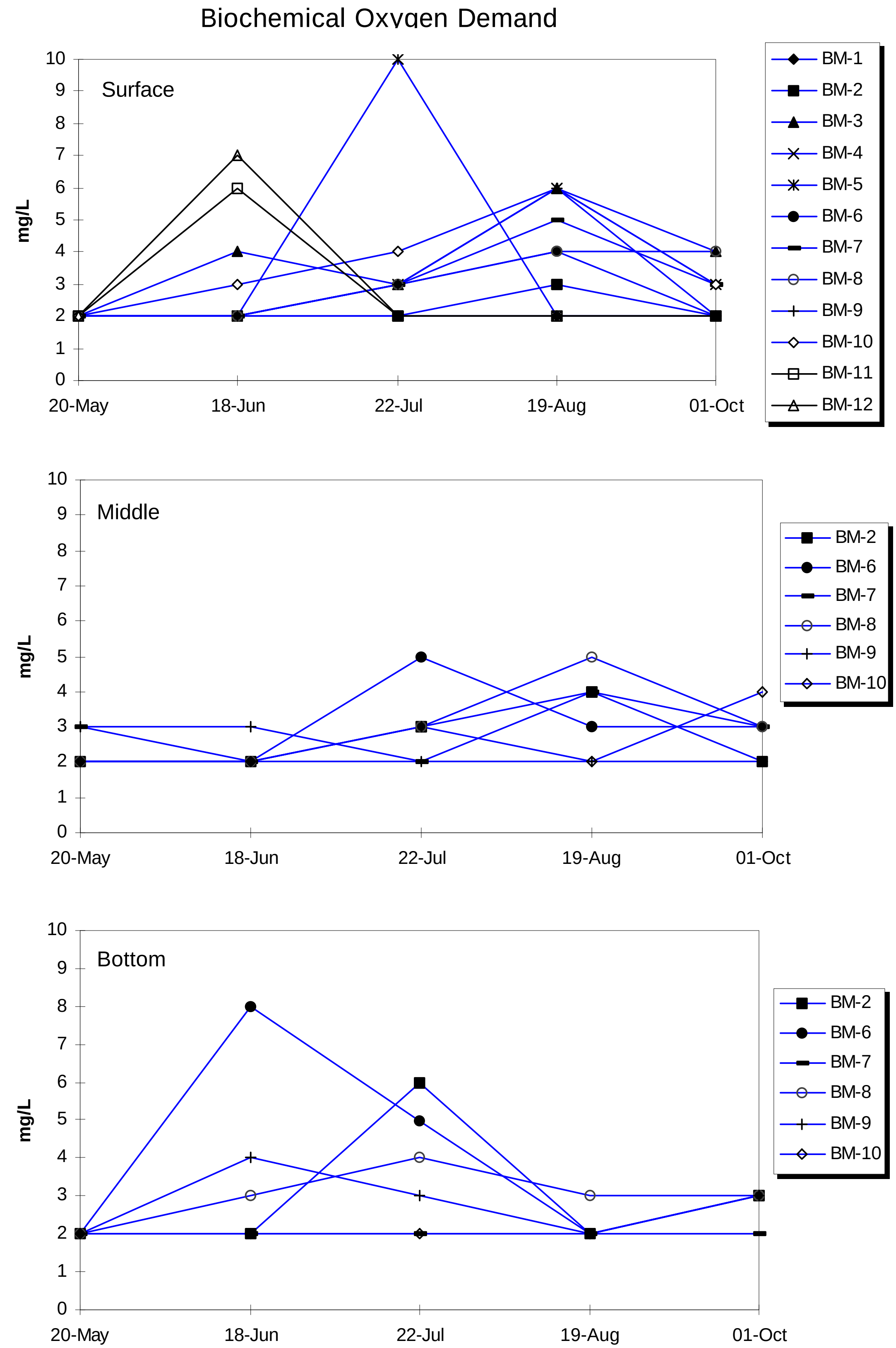

Figure 3-26. Biochemical oxygen demand in surface, middle, and bottom waters of Blue Marsh Reservoir 2002

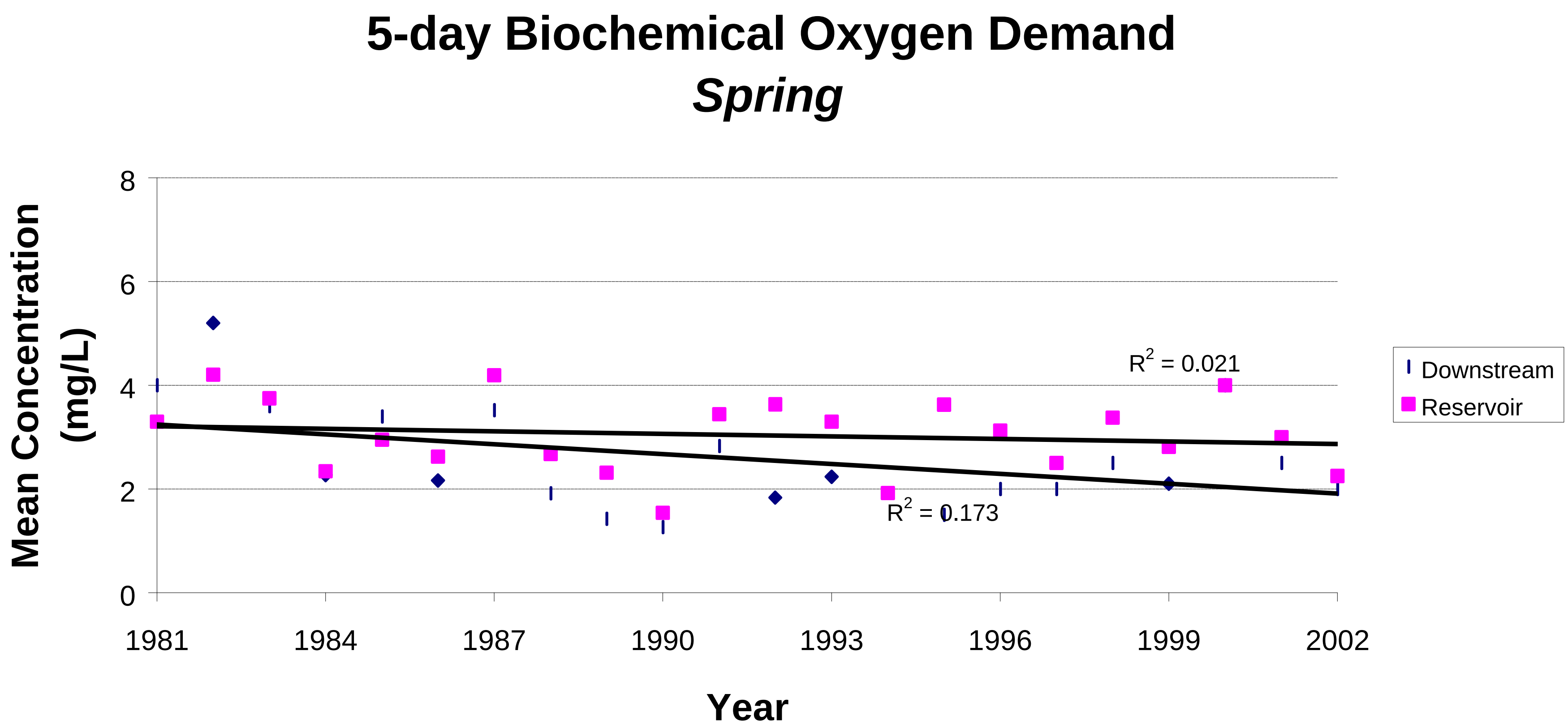

Figure 3-27. Seasonal trends for biochemical oxygen demand in surface water during spring at Blue Marsh Reservoir

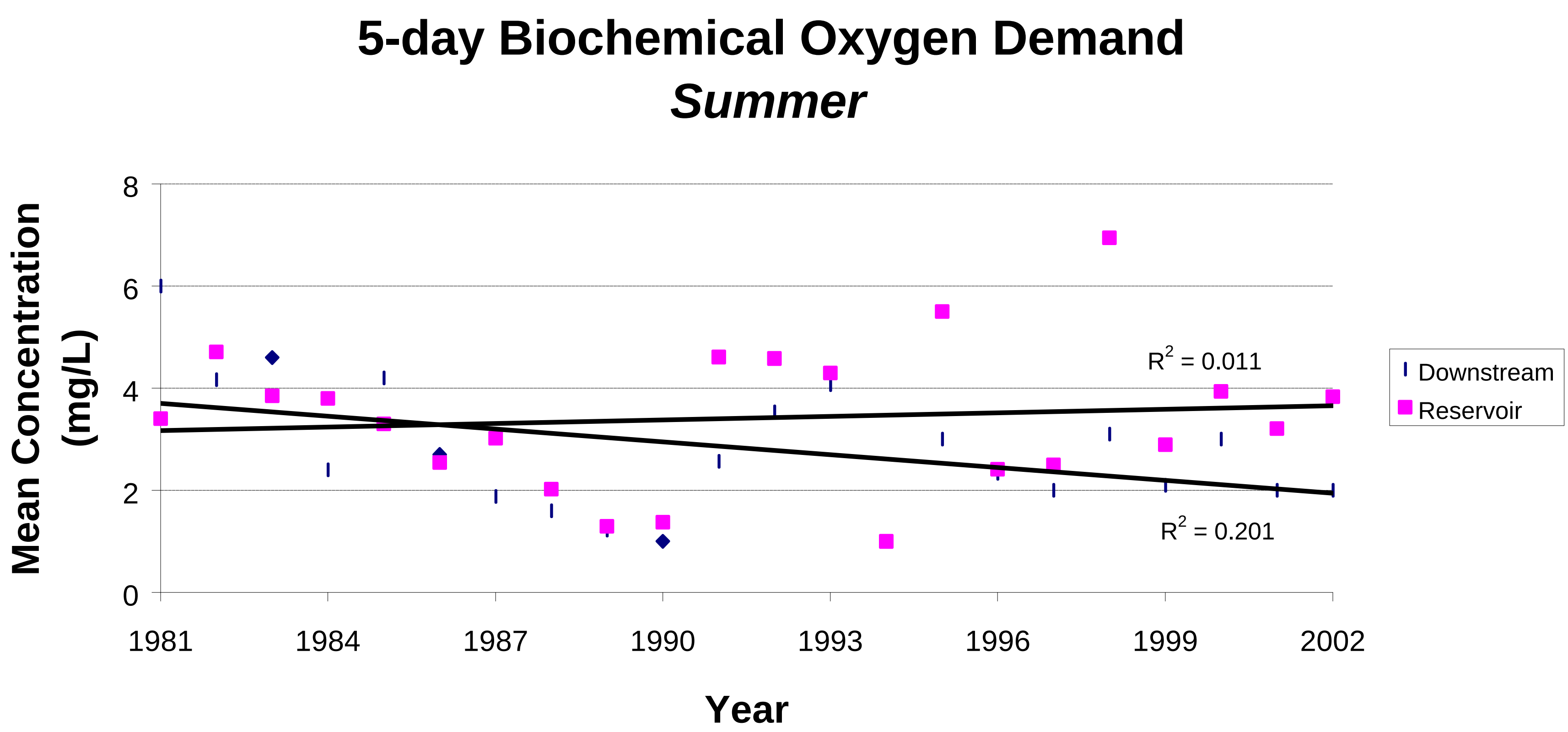

Figure 3-28. Seasonal trends for biochemical oxygen demand in surface water during summer at Blue Marsh Reservoir

Table 3-8. Seasonal trends of BOD at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant (at least $P < 0.05$).

Station	# of Years	Spring		Summer	
		P Level	Rate (mg/L/year)	P Level	Rate (mg/L/year)
Surface Water					
BM-1	21	NS	-0.0632	NS	-0.1046
BM-3	22	NS	0.0333	NS	0.0604
BM-4	22	NS	0.0133	NS	0.0238
BM-5	21	NS	-0.0283	NS	-0.0343
BM-9	17	NS	-0.1212	NS	-0.0613
Surface and Bottom Water					
BM-2	18	NS	-0.0208	NS	0.0654
BM-6	18	NS	-0.0104	NS	0.0589

3.2.11 Alkalinity

Alkalinity is a measure of the acid-neutralizing capacity of water. Alkalinity in the water column of Blue Marsh Reservoir was fairly consistent during 2002 (Fig. 3-29). Throughout the water column concentrations averaged 106 mg/L $CaCO_3$. Alkalinities in surface water at station BM-5 were generally higher than other measures. Throughout the monitoring period, concentrations at this station averaged 140 mg/L $CaCO_3$. Previously, it was thought that the water quality at station BM-5 was most likely influenced by discharges from the Bernville Wastewater Management Facility; however, station BM-11, located just below and station BM-12 located just above the treatment facility, both had lower than average concentrations of $CaCO_3$. Alkalinity at these stations averaged 87 mg/L throughout the sampling period. Alkalinity downstream of the reservoir (station BM-1) was slightly higher than other surface water measures upstream. Concentrations averaged 115 mg/L $CaCO_3$ and were probably influenced by the deeper water released from the Blue Marsh Reservoir dam.

Concentrations of alkalinity measured at Blue Marsh Reservoir were in compliance with PADEP water quality standards during 2002. The state water quality standard for alkalinity is a minimum concentration of 20 mg/L $CaCO_3$, except where natural conditions are less. The lowest concentration of alkalinity measured was 28 mg/L $CaCO_3$ during May at station BM-12.

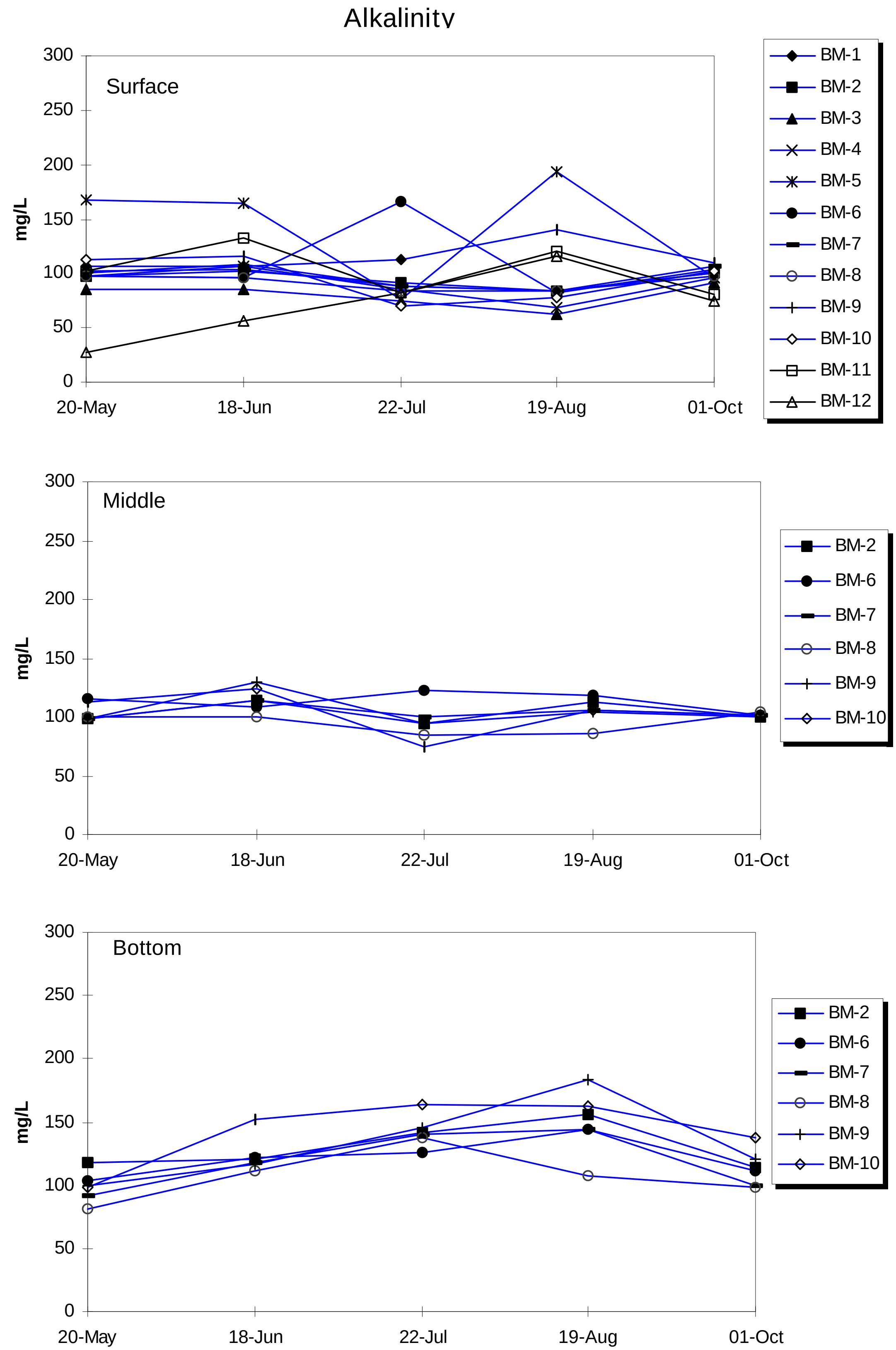

Figure 3-29. Alkalinity in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002. (The PADEP water quality standard for alkalinity is a minimum concentration of 20 mg/L.)

3.2.12 Chlorophyll *a*

Chlorophyll *a* is a measure of algal biomass. In 2002, chlorophyll *a* concentrations in the water column of Blue Marsh Reservoir were relatively low, especially in surface water (Fig. 3-30). Concentrations among most surface water stations averaged 4.5 mg/m^3 in May and June, increased to 9 mg/m^3 in August and decreased thereafter to 5.2 mg/m^3 in October. Concentrations in the lower water column averaged 4.7 mg/m^3 throughout the monitoring period. A maximum concentration throughout the monitoring period of 18.3 mg/m^3 was measured on the surface at station BM-5 in July and the minimum concentration of 0.5 mg/m^3 was measured on the surface at station BM-12 in August.

3.2.13 BTEX

Concentrations of benzene, toluene, ethylbenzene, o-xylene and m,p-xylenes (BTEX) in the surface waters of Blue Marsh Reservoir were low during 2002 (Table 3-9). These parameters were collected at stations BM-2, BM-6, BM-7, BM-8, BM-9, BM-10. With the exception of August, none of the parameters were detected throughout the sampling period. During August concentrations of benzene, toluene, o-xylene and m,p-xylenes ranged from 0.001 to 0.004 mg/L. The only station that BTEX parameters were not detected during the August sampling period was BM-8. Concentrations of Ethylbenzene were less than the method detection limit of 0.001 mg/L throughout the sampling period.

The concentrations of BTEX parameters measured at Blue Marsh Reservoir were in compliance with PADEP water quality standards during 2002. All of the concentrations measured were more than an order of magnitude less than PADEP water quality criteria for toxic substances. PADEP fish and aquatic life CCC's (criteria continuous concentrations) for the four parameters. The PADEP fish and aquatic life CCC's are as follows: benzene, 0.128 mg/L; ethylbenzene, 0.580 mg/L; toluene, 0.330 mg/L; and xylene, 0.211 mg/L (Pa. Code, Title 25, Chapter 16).

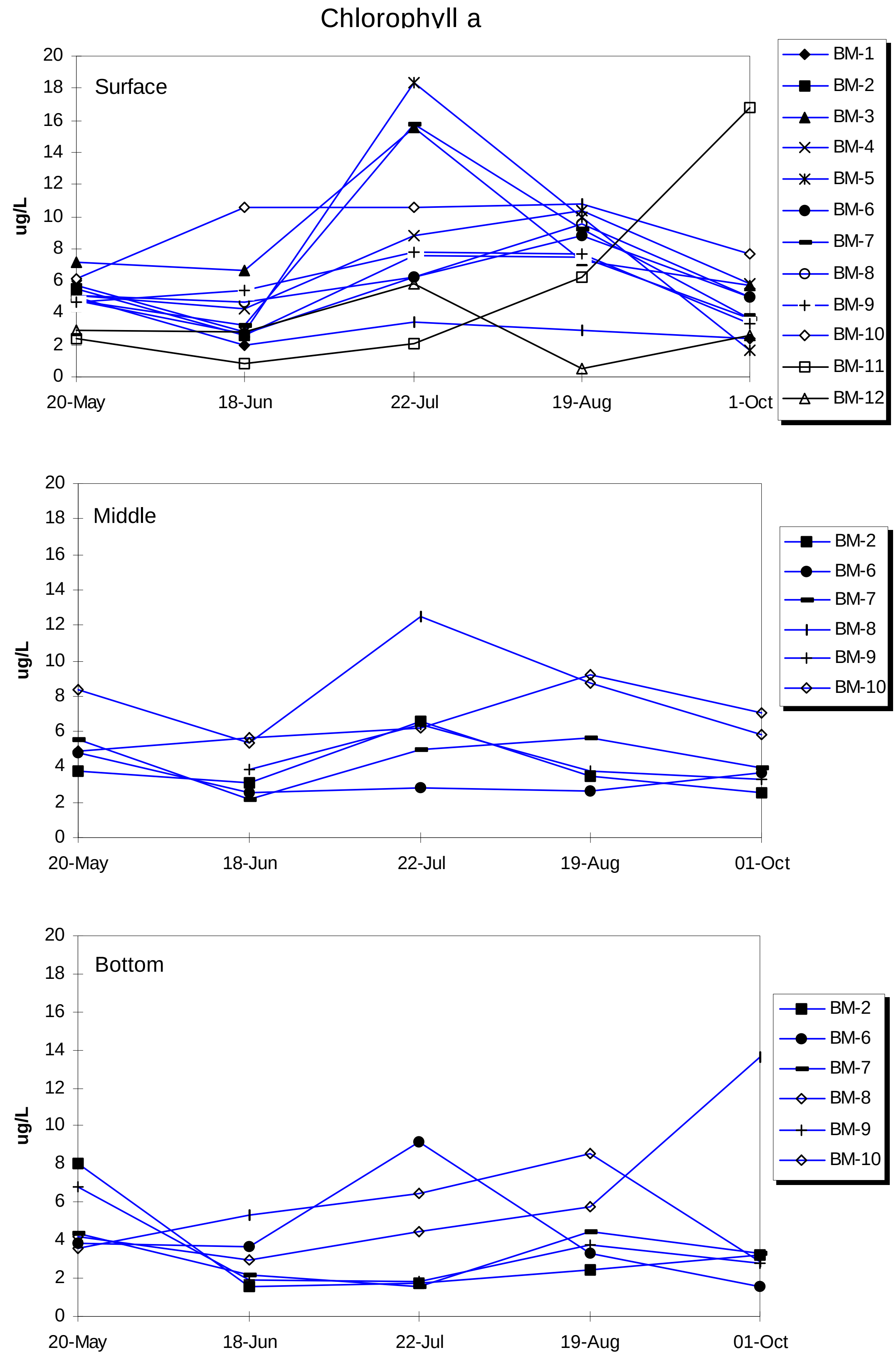

Figure 3-30. Chlorophyll *a* (mg/m^3) in surface, middle, and bottom waters of Blue Marsh Reservoir in 2002

Table 3-9. Concentrations of BTEX parameters (mg/l) measured in surface water at Blue Marsh Reservoir during 2002

Ethylbenzene	Date	Benzene	Ethylbenzene	Toluene	Xylene
BM-2	20 May	< 0.001	0.002	< 0.001	< 0.001
	18 June	< 0.001	< 0.001	< 0.001	< 0.001
	22 July	< 0.001	< 0.001	0.003	0.002
	19 August	< 0.001	< 0.001	< 0.001	0.002
	1 October	< 0.001	< 0.001	< 0.001	< 0.001
BM-6	20 May	< 0.001	0.002	< 0.001	< 0.001
	18 June	< 0.001	< 0.001	< 0.001	< 0.001
	22 July	< 0.001	< 0.001	0.002	0.004
	19 August	< 0.001	< 0.001	< 0.001	0.002
	1 October	< 0.001	< 0.001	< 0.001	< 0.001
BM-7	20 May	< 0.001	0.002	< 0.001	< 0.001
	18 June	< 0.001	< 0.001	< 0.001	< 0.001
	22 July	0.001	< 0.001	0.002	0.007
	19 August	0.001	< 0.001	< 0.001	0.002
	1 October	< 0.001	< 0.001	< 0.001	< 0.001
BM-8	20 May	< 0.001	0.002	< 0.001	< 0.001
	18 June	< 0.001	< 0.001	< 0.001	< 0.001
	22 July	< 0.001	< 0.001	< 0.001	< 0.001
	19 August	< 0.001	< 0.001	< 0.001	0.001
	1 October	< 0.001	< 0.001	< 0.001	< 0.001
BM-9	20 May	< 0.001	0.002	< 0.001	< 0.001
	18 June	< 0.001	< 0.001	1.950	1.460
	22 July	0.001	< 0.001	0.001	0.007
	19 August	0.001	< 0.001	< 0.001	0.001
	1 October	< 0.001	< 0.001	< 0.001	< 0.001
BM-10	20 May	< 0.001	0.002	< 0.001	< 0.001
	18 June	< 0.001	< 0.001	< 0.001	< 0.001
	22 July	< 0.001	< 0.001	< 0.001	< 0.001
	19 August	< 0.001	< 0.001	< 0.001	< 0.001
	1 October	< 0.001	< 0.001	< 0.001	< 0.001

3.3 TROPHIC STATE DETERMINATION

Carlson's (1977) trophic state index (TSI) is a method of quantitatively expressing the magnitude of eutrophication for a lake. The trophic state analysis calculates separate indices for eutrophication based on measures of total phosphorus, chlorophyll *a*, and secchi disk depth. Index values for each parameter range on the same scale from 0 (least enriched) to 100 (most enriched). The resulting indices can also be compared to qualitative threshold values that correspond to levels of eutrophication: oligotrophic (TSI < 40), mesotrophic (TSI > 40), mesoeutrophic (TSI's from 50 to 60), and eutrophic (TSI > 60).

TSI's calculated for measures of secchi disk depth consistently classified Blue Marsh Reservoir as mesoeutrophic during 2002 (Fig. 3-31). TSI values ranged from 55 to 59 in the beginning of the summer for secchi disk depth. In August, the TSI value of 69 was in the eutrophic level. In October, the TSI value decreased back to a mesoeutrophic level of 58.

TSI's calculated for measures of total phosphorus classified Blue Marsh Reservoir as eutrophic during 2002(Fig. 3-31). TSI values were usually around 63 except for July, which had a value of 54.

TSI values calculated for measures of chlorophyll *a* classified Blue Marsh Reservoir as mesotrophic in May and June with values of 47 and 46 (Fig. 3-31). In July and August, TSI values were in the mesoeutrophic level of 52 and 54. The TSI values for October went back to mesotrophic in October.

Considering the TSI results for all three parameters, it might be concluded that the condition of Blue Marsh Reservoir was mesotrophic, mesoeutrophic and eutrophic during the beginning and the end of the summer for 2002. During the middle of the summer, the lake would be considered to be meoeutrophic. However, Carlson (1977) warned against averaging TSI values estimated for different parameters, and instead suggested giving priority to chlorophyll *a* in the summer and to phosphorus in the spring, fall, and winter. With this in mind, our estimation of the trophic state of the reservoir based on TSI's was borderline mesoeutrophic and mesotrophic.

The EPA (1983) also provides criteria for defining the trophic conditions of lakes of the North Temperate Zone based on concentrations of total phosphorus, chlorophyll *a*, and secchi depth (Table 3-10). Based on these ranges of classification, Blue Marsh Reservoir was overwhelmingly eutrophic throughout the 2002 monitoring period. Concentrations of total phosphorus were often three times greater than their respective eutrophic minimum criteria borderlines (20-µg/L). Secchi disc depths ranged from 0.53 to 1.41-m, significantly less than the eutrophic criteria borderline of 2-m.

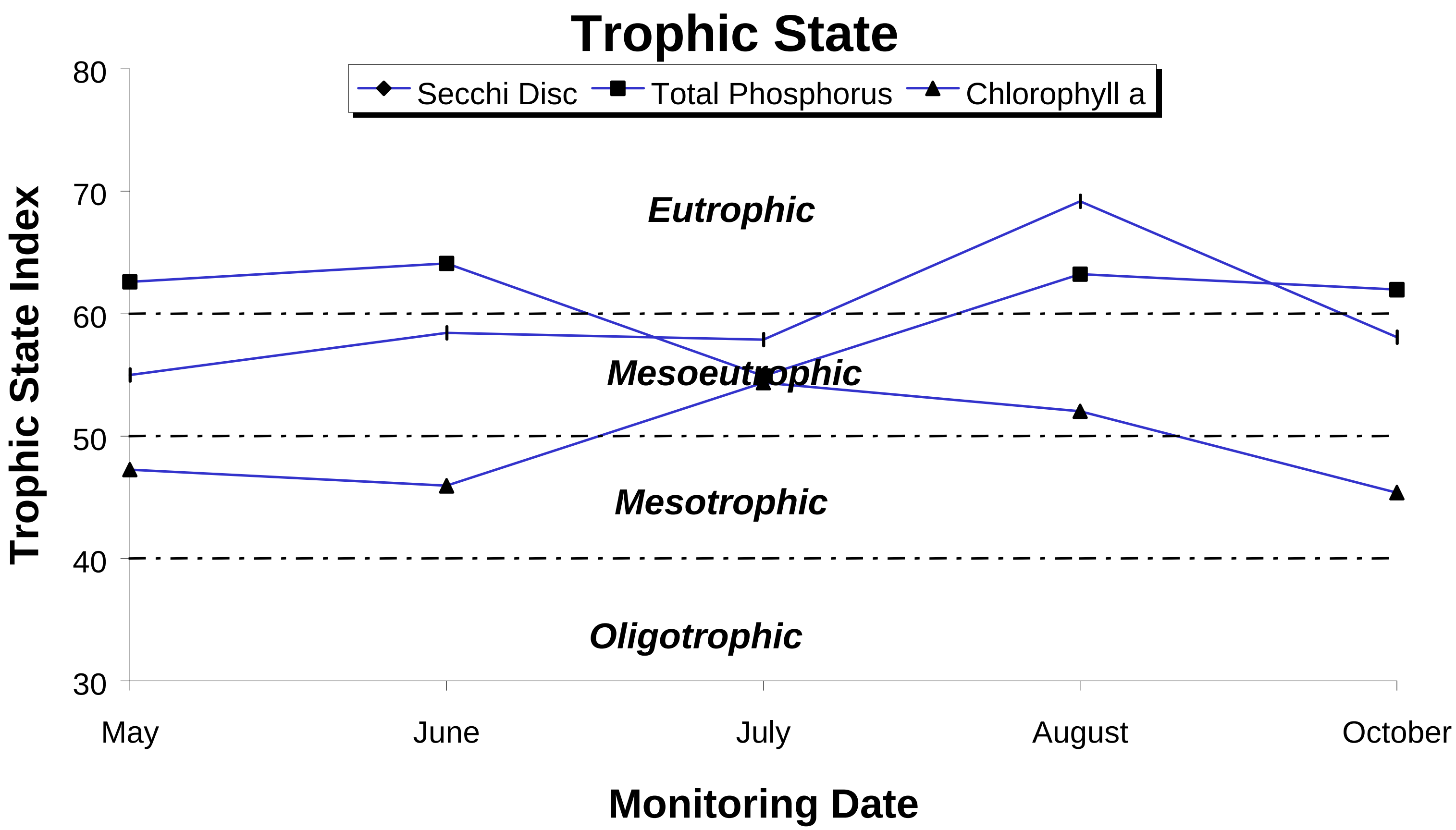

Figure 3-31. Trophic state indices calculated from secchi disk depth and concentrations of total phosphorus and chlorophyll *a* at Blue Marsh Reservoir in 2002

In comparison with these criteria, Blue Marsh Reservoir was classified eutrophic for 2002. All of the monthly averages for chlorophyll *a*, secchi disk depth, and total phosphorus scored in the eutrophic category.

Table 3-10. EPA trophic classification criteria and average monthly measures for Blue Marsh Reservoir in 2002

Water Quality Variable	**Oligo-trophic**	**Meso-trophic**	**Eutrophic**	20 May	18 June	22 July	19 August	1 October
Total phos. (µg/l)	< 10	10-20	> 20	58	64	34	60	55
Chlorophyll (mg/m^3)	< 4	4-10	> 10	5.48	4.79	11.31	8.93	4.54
Secchi depth (m)	> 3.7	2-4	< 2	1.41	1.11	1.16	0.53	1.14

3.4 RESERVOIR COLIFORM BACTERIA MONITORING

In 2002, Blue Marsh Reservoir was monitored for three parameters of coliform bacteria contamination: total coliform, fecal coliform, and fecal streptococcus at only stations BM-11 and BM-12 (Table 3-11; Figs. 3-32, 3-33, and 3-34). The parameters were monitored at all surface water stations including downstream of the reservoir (station BM-1).

Approximately fifty percent of total coliform counts exceed 200 clns/100-ml at most monitoring stations of Blue Marsh Reservoir (Fig. 3-32; Table 3-11). Higher counts were usually observed at stations BM-1, BM-5, BM-11, and BM-12, which are the upstream tributaries. Additionally, stations BM-2, BM-4, BM-6, BM-7, BM-8, and BM-9 had higher counts only during the October sampling.

Fecal coliform contamination in surface waters of Blue Marsh Reservoir ranged from the 10 clns/100-ml detection limit to a high of 7250 clns/100-ml during 2002 (Fig. 3-33; Table 3-11). More than half of the stations had counts less than 200-clns/100-ml. However, stations BM-1, BM-5, BM-11, and BM-12 had relatively high counts throughout the monitoring period.

Fecal streptococcus contamination was generally low in Blue Marsh Reservoir surface waters was monitored at only stations BM-11 and BM-12 during 2002 (Fig. 3-34; Table 3-11). The only time that fecal streptococcus counts exceeded 200 clns/100-ml was at station BM-11 during the May sampling event.

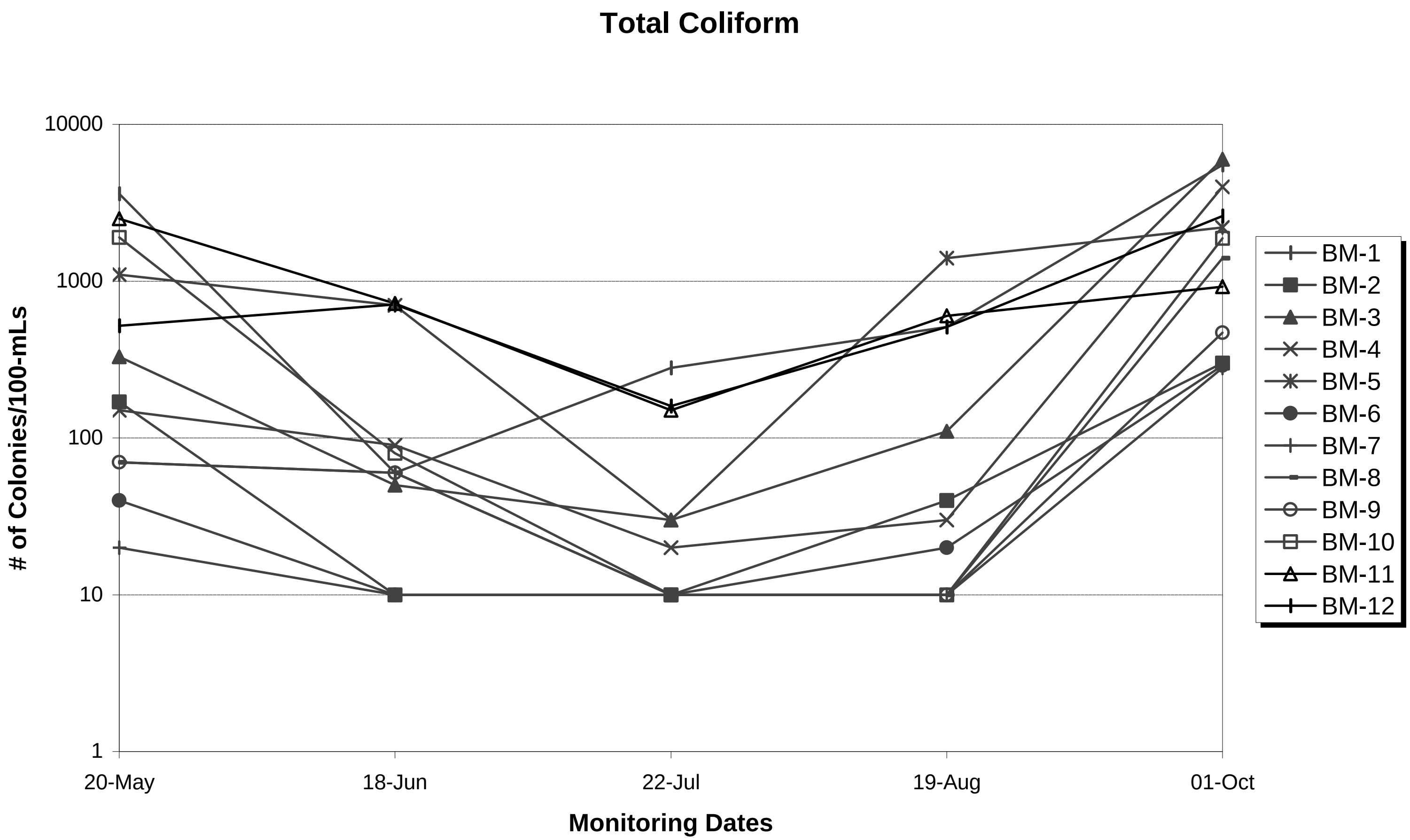

Figure 3-32. Total coliform counts in surface waters of Blue Marsh Reservoir in 2002

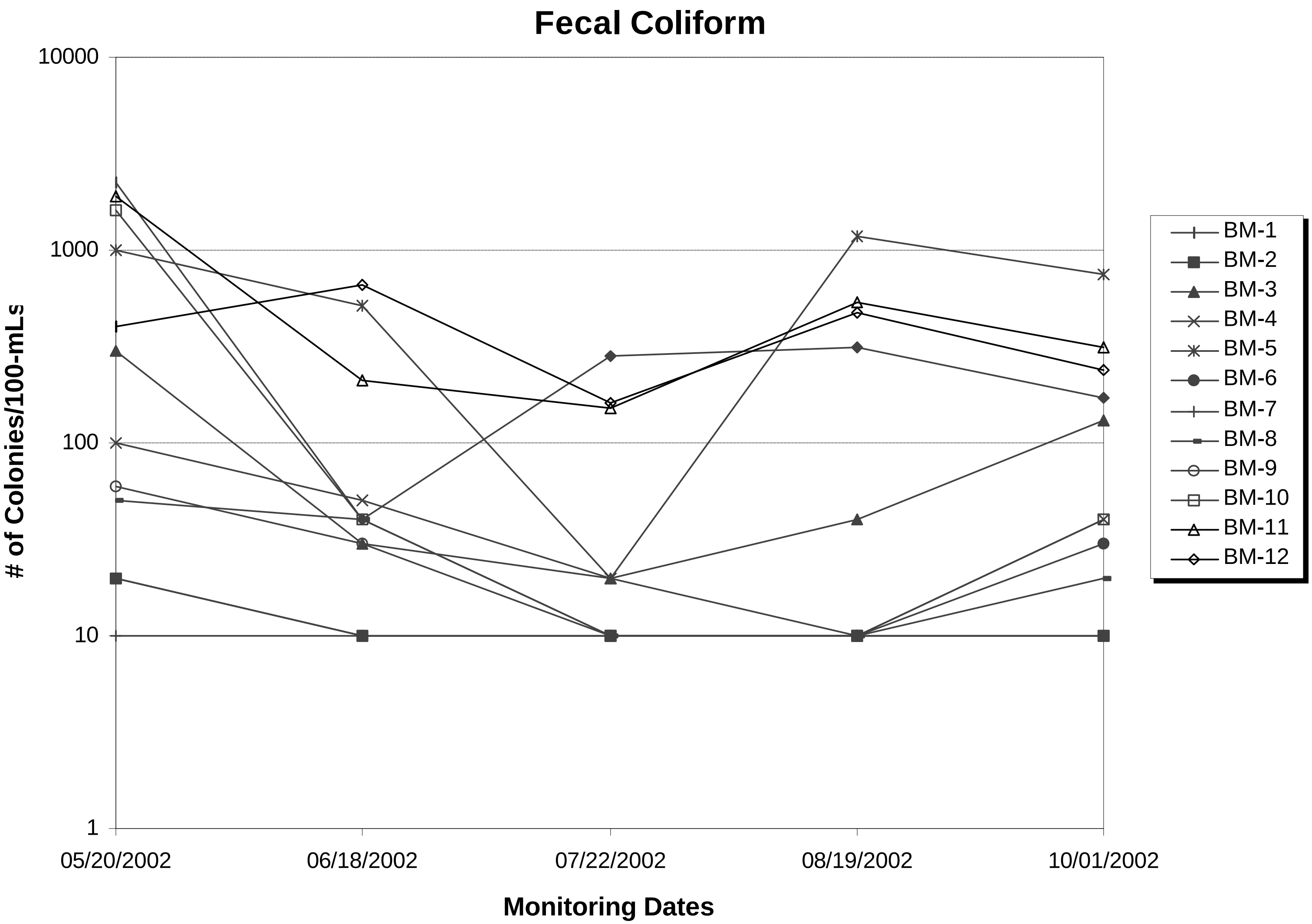

Figure 3-33. Fecal coliform counts in surface waters of Blue Marsh Reservoir in 2002. (PADEP water quality standard for fecal coliform is less than 200 colonies/100mls.)

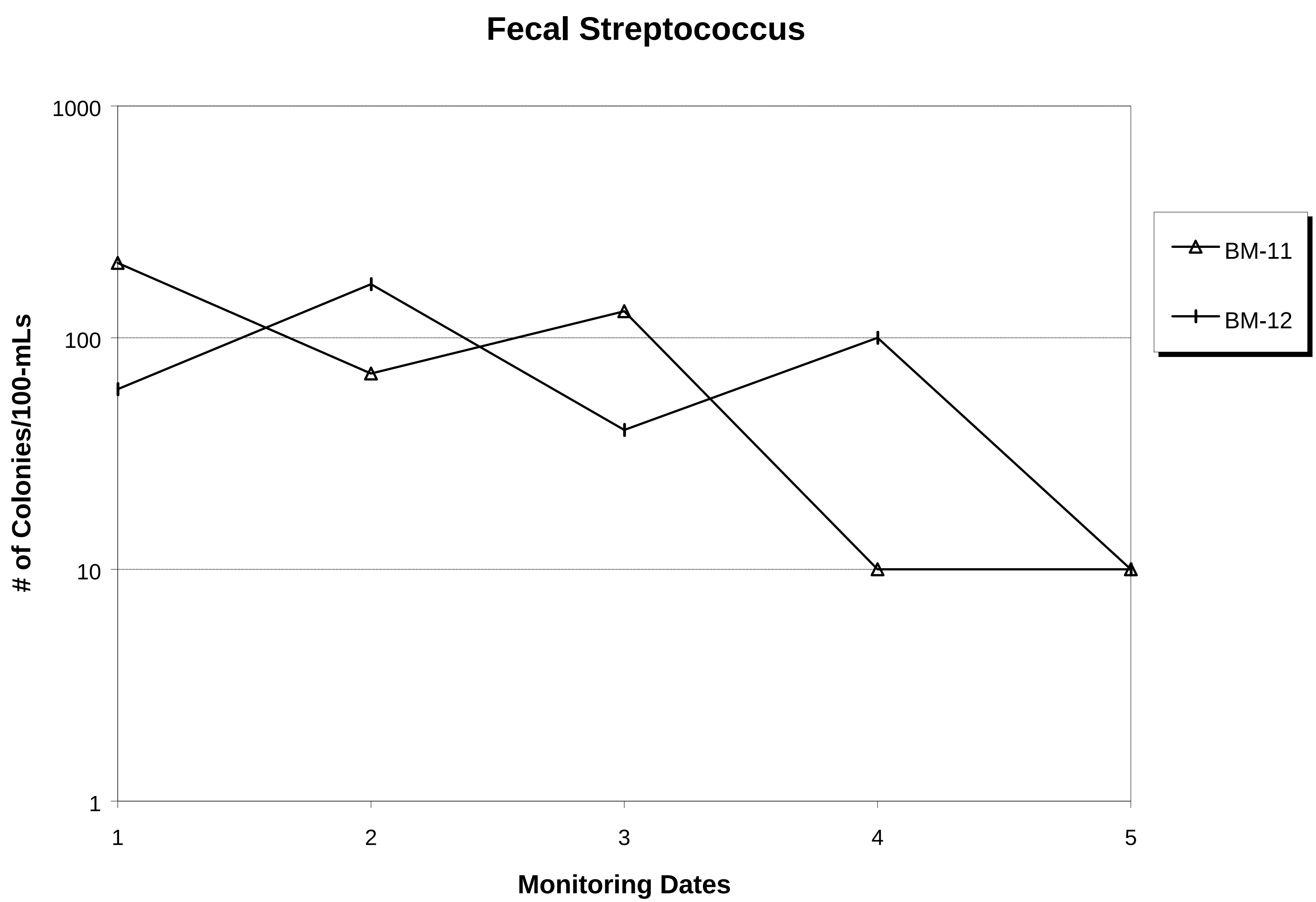

Figure 3-34. Fecal streptococcus counts in surface waters of Blue Marsh Reservoir in 2002

Table 3-11. Bacteria counts (colonies/100 ml) at Blue Marsh Reservoir during 2002. Shaded values exceed the Pennsylvania Department of Health water quality standard for bathing beach of 1,000 fecal coliform colonies/100-ml.

STATION	DATE	Total Coliform	Fecal Coliform (FC)	Fecal Strep (FS)	FC/FS
BM-1S	05/20/2002	3600	2250		
	06/18/2002	60	40		
	07/22/2002	280	280		
	08/19/2002	510	310		
	10/01/2002	5500	170		
BM-2S	05/20/2002	170	20		
	06/18/2002	< 10	< 10		
	07/22/2002	< 10	< 10		
	08/19/2002	40	< 10		
	10/01/2002	300	< 10		
BM-3S	05/20/2002	330	300		
	06/18/2002	50	30		
	07/22/2002	30	20		
	08/19/2002	110	40		
	10/01/2002	6000	130		
BM-4S	05/20/2002	150	100		
	06/18/2002	90	50		
	07/22/2002	20	20		
	08/19/2002	30	10		
	10/01/2002	4000	40		
BM-5S	05/20/2002	1100	1000		
	06/18/2002	700	520		
	07/22/2002	30	20		
	08/19/2002	1400	1180		
	10/01/2002	2200	750		
BM-6S	05/20/2002	40	20		
	06/18/2002	< 10	< 10		
	07/22/2002	< 10	< 10		
	08/19/2002	20	< 10		
	10/01/2002	290	30		
BM-7S	05/20/2002	20	10		
	06/18/2002	< 10	< 10		
	07/22/2002	< 10	< 10		
	08/19/2002	10	< 10		
	10/01/2002	280	10		
BM-8S	05/20/2002	70	50		
	06/18/2002	60	40		
	07/22/2002	10	10		
	08/19/2002	< 10	< 10		
	10/01/2002	1400	20		

Table 3-11. (Continued)

STATION	DATE	Total Coliform	Fecal Coliform (FC)	Fecal Strep (FS)	FC/FS
BM-9S	05/20/2002	70	60		
	06/18/2002	60	30		
	07/22/2002	< 10	< 10		
	08/19/2002	< 10	< 10		
	10/01/2002	470	10		
BM-10	05/20/2002	1900	1600		
	06/18/2002	80	40		
	07/22/2002	< 10	< 10		
	08/19/2002	< 10	< 10		
	10/01/2002	1880	40		
BM-11	05/20/2002	2500	1900	210	9.05
	06/18/2002	720	210	70	3.00
	07/22/2002	150	150	130	1.15
	08/19/2002	600	540	10	54.00
	10/01/2002	920	310	< 10	NC
BM-12	05/20/2002	520	400	60	6.67
	06/18/2002	710	660	170	3.88
	07/22/2002	160	160	40	4.00
	08/19/2002	510	470	100	4.70
	10/01/2002	2600	240	< 10	NC

In considering the spatial distribution of the results of the fecal coliform and total coliform bacteria parameters, the data suggests that the source of contamination for Blue Marsh Reservoir derives from either Northkill or Tuplehocken Creeks. Average counts among the parameters were often several times greater than at any other surface water station (Table 3-11). Average counts below the confluence of Northkill or Tuplehocken Creeks at BM-5 were 890 clns/100-ml whereas average counts from Northkill Creek (BM-11 and BM-12) were 722 clns/100-ml. The high counts at station BM-5, BM-11, and the upstream station BM-12 suggest that the Bernville Wastewater Treatment Facility may not be the main source of bacterial contamination as indicated in previous reports. In addition, the highest fecal coliform and total coliform counts were downstream of the reservoir (BM-1), averaging 1300 clns/100-ml.

With respect to PADEP water quality standards, coliform bacteria contamination were over criteria at stations BM-1, BM-5, BM-10, and BM-11 in the surface waters of Blue Marsh Reservoir during 2002 (Table 3-11; Fig. 3-35). The PADEP standard for bacteria during the swimming season (from 1-May to 30-September) is a geometric mean not greater than 200-clns/100-ml calculated for fecal coliform samples collected on consecutive days. Given that our general monitoring is completed in one day, we calculated the geometric mean based on surface water samples for the entire reservoir. Throughout the monitoring period, the geometric means calculated for each monitoring day were less than the PADEP water quality standard (Table 3-12).

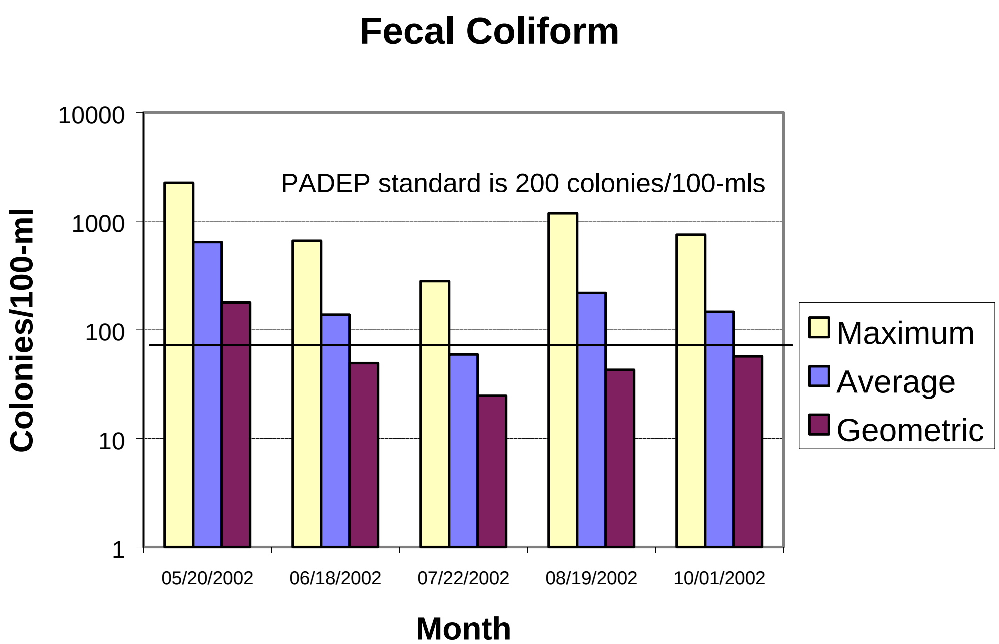

Figure 3-35. Maximum, average, and geometric mean of fecal coliform counts (colonies/100-ml) for all)

Table 3-12. Summary statistics of fecal coliform counts (colonies/100-ml) among all stations of Blue Marsh Reservoir during 2002. (PADEP water quality standard for fecal coliforms is a geometric mean not greater than 200 colonies/100-ml)

Date	Geometric Mean	Arithmetic mean	Maximum Count
05/20/2002	177.6	642.5	2250.0
06/18/2002	49.3	137.5	660.0
07/22/2002	24.8	59.2	280.0
08/19/2002	42.7	217.5	1180.0
10/01/2002	57.0	146.7	750.0

Flow data from a USGS gauging station within the Blue Marsh Reservoir watershed (Bernville) were analyzed to qualitatively correlate precipitation events with coliform bacteria contamination (Figs. 2-2 through 2-5). Overall, coliform contamination did not appear to strongly correlate with streamflow patterns. On most dates, monitoring was conducted near baseflow conditions. Sampling in May and October was coincident with a flow peak and may be correlated with the high values observed at all of the stations.

Analyses of the long-term trends based on 21 years of fecal coliform monitoring in Blue Marsh Reservoir suggest that, during the summer, levels of bacteria have been decreasing in the reservoir, but increasing at downstream station BM-1 (Figs. 3-36 and 3-37). The regression was stronger for the reservoir summer trend ($R^2 = 0.57$; $P < 0.00005$), and indicated an average yearly decrease of approximately 100 colonies/100-ml. The regression for the downstream summer trend was moderately strong ($R^2 = 0.33$; $P < 0.005$) and indicated a yearly rate of increase of about 10 colonies/100-ml. No trends were observed during spring within either the reservoir or at the downstream station (Fig. 3-36).

Seasonal trend analyses for total and fecal coliform contamination in surface water were also calculated for individual stations using the Mann-Kendall Statistic. The tests were conducted for spring (April through June) and summer (July through October) seasons for 7 stations with extensive historical data. Total coliform trends were only found at stations BM-3 and BM-4 to be significantly decreasing (Tables 3-13 and 3-14). At station BM-3, total coliform densities have decreased in spring and summer seasons at the rates of 248 and 648 colonies/100-ml/year, respectively. Similarly for BM-4, spring counts have decreased at rates of 78 colonies/100-ml/year. There were many significant trends of fecal coliform found during the spring and summer seasons. Station BM-3 was found to be decreasing during both seasons at rates of 47 and 89 colonies/100-ml/year. Station BM-5 showed a significant increase at a rate of 45 colonies/100-ml/year during the spring. The only stations that were not significantly increasing or decreasing in fecal coliform based on the addition of this year's data were station BM-2 and BM-9.

Table 3-13. Seasonal trends of total coliform counts in surface water at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant at P = 0.05.

Station	# of Years (Spring/Summer)	Spring		Summer	
		P Level	Rate	P Level	Rate
BM-1	21/22	NS	5.7353	NS	16.667
BM-2	22	NS	0.2941	NS	-5.3863
BM-3	22	< 0.01	-247.75	< 0.01	-647.92
BM-4	22	< 0.05	-77.50	NS	-57.667
BM-5	22	NS	49.71	NS	-107.50
BM-6	16	NS	0.4129	NS	2.4748
BM-9	16	NS	0.9808	NS	0.2344

The ratio of fecal coliform to fecal streptococcus counts can be used to cursorily identify sources of bacteria contamination (McComas 1993). The ratio is characteristic for several animal species and certain waste disposal practices; for human waste, the ratio is 4 to 1. Fecal streptococcus was only tested at stations BM-11 and BM-12. In October,

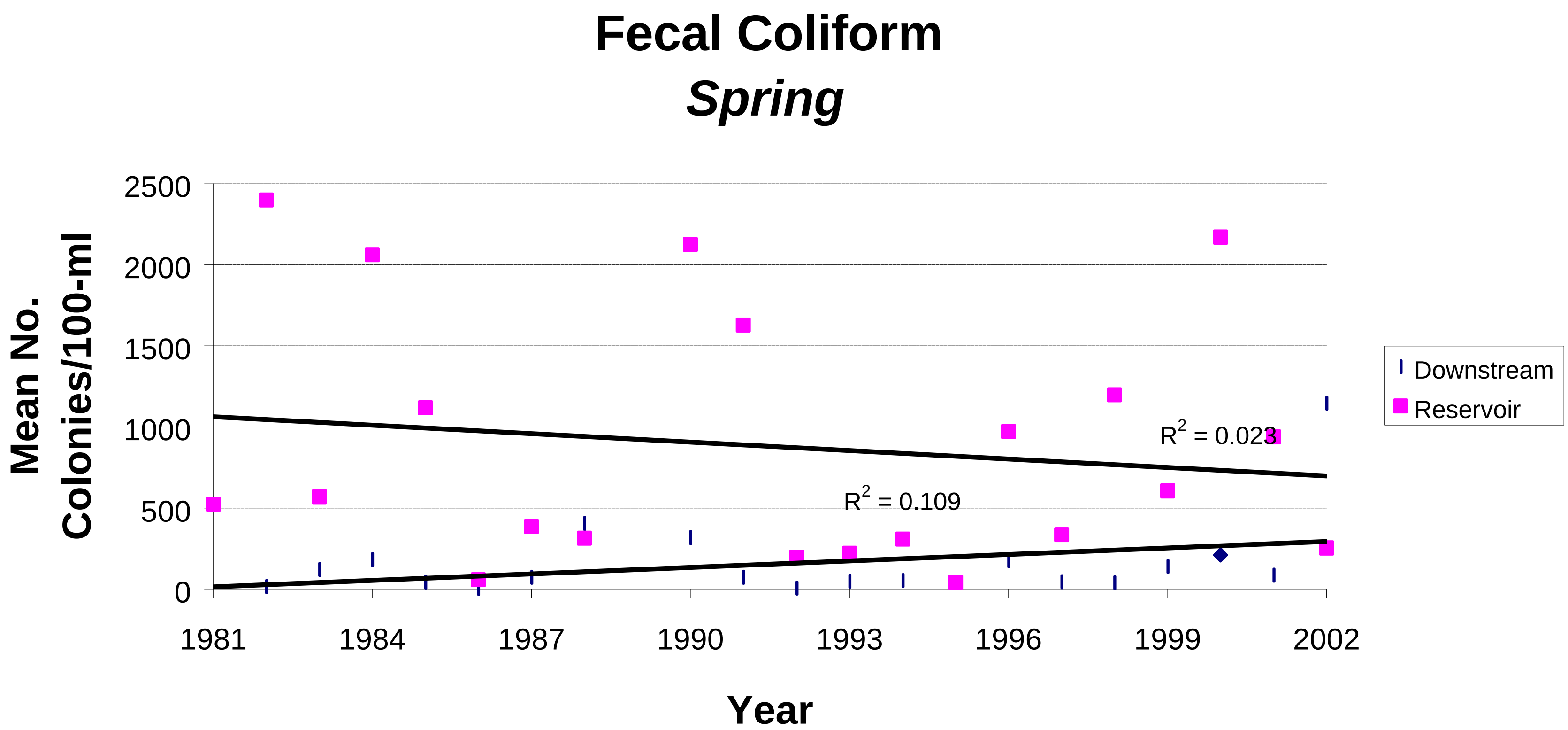

Figure 3-36. Seasonal trends for fecal coliform in the spring at Blue Marsh Reservoir

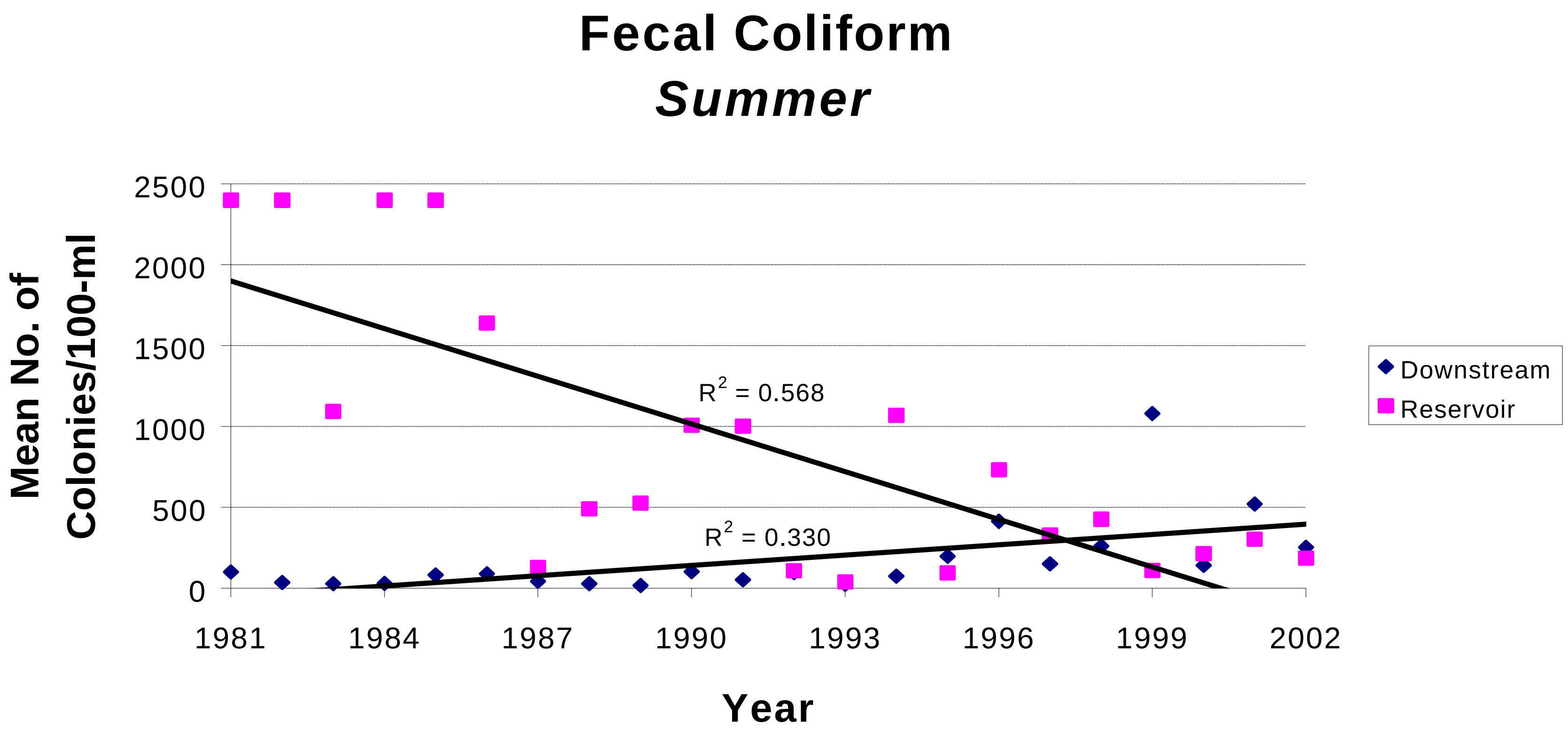

Figure 3-37. Seasonal trends for fecal coliform in the summer of Blue Marsh Reservoir

the ratio was limited to the extent that counts at both stations were at or less than method detection limits for one or both coliform parameters. Out of a total of 10 perspective ratios, only 8 were calculated and ranged from 1.15 to 54.00 (Table 3-11). Four of the ratios fell within the range one would expect for human waste sources.

Table 3-14. Seasonal trends of fecal coliform counts in surface water at individual stations of Blue Marsh Reservoir calculated with the Mann-Kendall Statistic. Shaded values are significant at P=0.05.

Station	# of Years (Spring/Summer)	Spring		Summer	
		P Level	Rate	P Level	Rate
BM-1	20/21	NS	0.6979	<0.05	7.7500
BM-2	21/22	NS	0.0729	NS	0.1944
BM-3	21/22	<0.01	-47.3177	< 0.01	-88.929
BM-4	21/22	<0.05	-12.8333	NS	-13.048
BM-5	21/22	< 0.05	45.0625	NS	-0.1667
BM-6	15/16	<0.05	0.4643	<0.01	1.0188
BM-9	15/16	NS	0.6000	NS	0.5083

3.5 SWIMMING BEACH BACTERIA MONITORING

3.5.1 Weekly Swimming Beach Coliform Bacteria Monitoring

Weekly coliform bacteria monitoring was conducted at the public swimming beach of the Dry Brooks day use area of Blue Marsh Reservoir to gauge compliance with Pennsylvania Department of Health bathing beach water quality standards. The bathing beach contamination standard, like the PADEP swimming season water quality standard, is based on a geometric mean among fecal coliform samples collected over 5 consecutive days of less than 200 colonies/100-ml, but also stipulates that no single sample should exceed 1,000 colonies/100-ml. Samples for coliform analysis were collected twice weekly from 3 fixed stations on each date. All of the coliform bacteria counts for the weekly swimming beach monitoring at Blue Marsh Reservoir are summarized in Appendix Table D-1.

Fecal coliform contamination was consistently high at the swimming beach area of Blue Marsh Reservoir during 2002 (Table 3-15; Figs. 3-38 and 3-39). Throughout the 20 weeks of monitoring, the geometric means calculated for each of the 3 surface water stations at times exceeded the water quality standard. Station SB1 exceeded the standard during the fourteenth week of the sampling period and ranged as high as 220 colonies/100-ml. During the thirteenth week, station SB2 and SB3 exceeded the standard and ranged as high as 257 colonies/100-ml. Station SB3 continued to exceed the standard

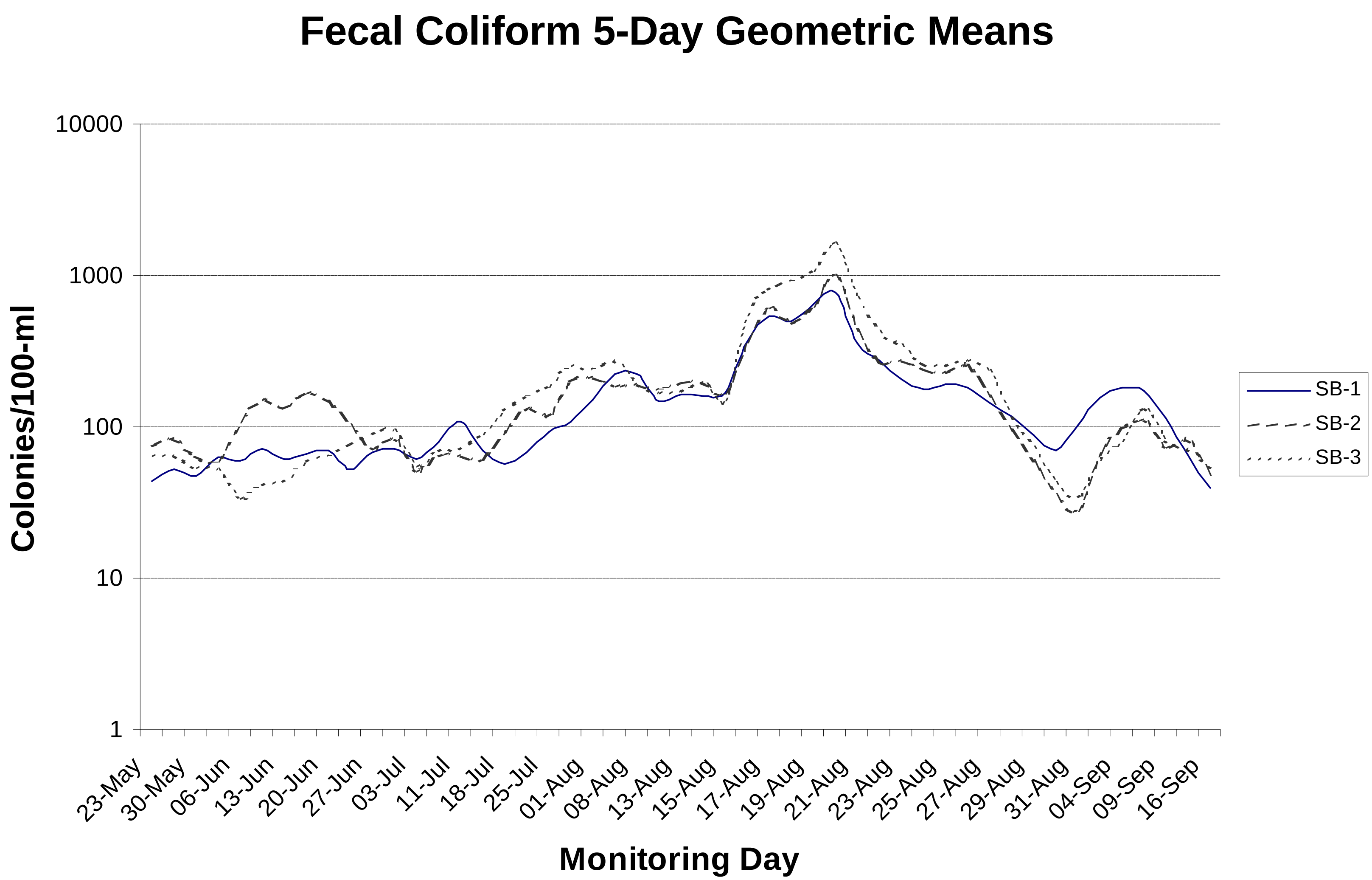

Figure 3-38. Five-day geometric means for fecal coliform from May until October 2002 at Blue Marsh Reservoir

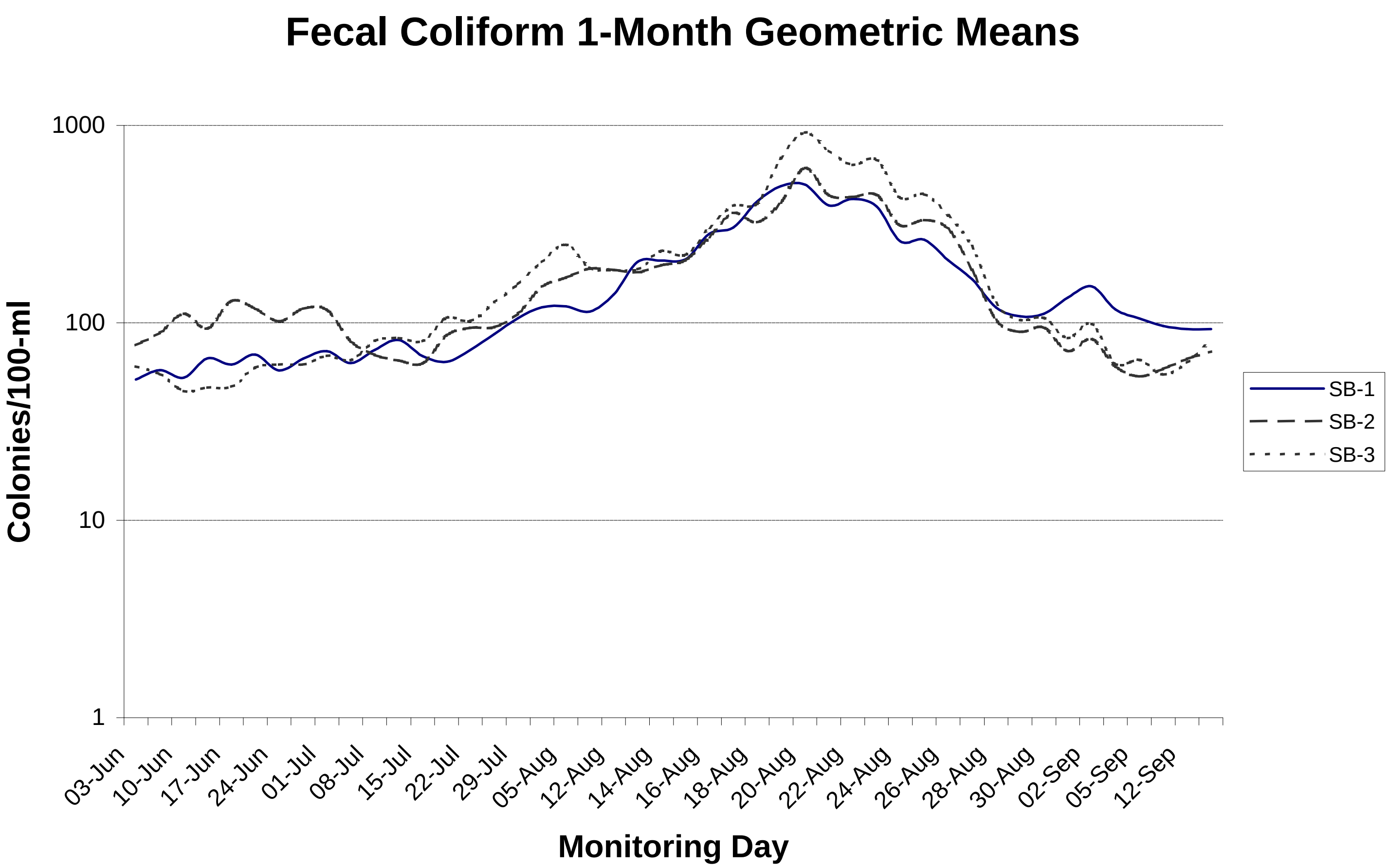

Figure 3-39. One-month geometric means for fecal coliform from June until October 2002 at Blue Marsh Reservoir.

in the beginning of the fourteenth week with a count of 271 colonies/100-ml. On 16 August, all three stations exceeded the water quality standard. Station SB1 continued to exceed the standard until 23 August with counts ranging from 207 to 768 colonies/100-ml. Station SB2 continued to exceed the standard three more days after SB1. The 5-day geometric mean for SB1 had a low count of 230 colonies/100-ml and a high count of 990 colonies/100-ml. Station SB3 exceeded the standard from 16 August until 27 August. This station had the highest count of 1630 colonies/100-ml. The high bacterial counts prompted the USACE to initiate condition 2 and 3 sampling where samples are collected daily. Condition 3 sampling remained in effect until the end of August 2002. Based on these samples, the swimming beach was closed approximately 12 August until 3 September.

Table 3-15. Maximum counts and 5-day running geometric means of the 3 swimming beach stations of Blue Marsh Reservoir and counts from upstream station BM-11 and BM-12 during 2002. Shaded values indicate results that were not in compliance with Pennsylvania Department of Health water quality standards for bathing beaches: maximum count greater than 1,000 colonies/100-ml; 5-day geometric mean greater than 200 colonies/100-ml.

		Maximum	5-Day Geometric Means				
Week	Date	Count	sb1	sb2	sb3	BM-11	BM-12
1	09-May-02	60				1200	700
	13-May-02	150					
2	16-May-02	50				250	250
	20-May-02	360					
3	23-May-02	140	43.73	74.87	65.11	650	560
	28-May-02	130	52.94	82.92	65.11		
4	30-May-02	60	47.80	64.54	54.21	750	400
	03-Jun-02	130	63.08	59.21	51.84		
5	06-Jun-02	190	59.55	106.70	33.66	2800	2600
	10-Jun-02	840	71.53	152.69	41.93		
6	13-Jun-02	70	61.28	132.92	43.24	2600	2450
	17-Jun-02	280	66.45	168.26	58.85		
7	20-Jun-02	70	69.49	148.67	63.82	7600	5800
	24-Jun-02	80	52.66	102.77	77.65		
8	27-Jun-02	180	68.04	70.76	89.19	1280	1520
	01-Jul-02	120	72.07	84.31	93.79		
9	03-Jul-02	40	61.28	50.47	55.33	120	80
	08-Jul-02	230	78.27	64.03	68.92		
10	11-Jul-02	150	107.99	64.03	70.56	660	< 10
	15-Jul-02	210	69.59	60.76	90.66		
11	18-Jul-02	960	57.19	92.09	129.24	560	640
	22-Jul-02	90	67.26	131.78	161.00		
12	25-Jul-02	790	91.46	119.33	183.90	530	1050

Table 3-15. (Continued)							
		Maximum	5-Day Geometric Means				
Week	Date	Count	sb1	sb2	sb3	BM-11	BM-12
13	29-Jul-02	480	108.35	203.24	257.03		
	01-Aug-02	160	152.37	210.79	243.43	950	1410
14	05-Aug-02	910	220.40	187.17	271.22		
	08-Aug-02	90	220.40	193.03	189.54	730	1120
15	12-Aug-02	180	145.78	176.71	165.93		
	13-Aug-02	750	163.96	197.50	170.51		
	14-Aug-02	340	160.87	197.50	198.26		
	15-Aug-02	240	168.56	165.65	151.87	660	500
	16-Aug-02	6100	361.80	368.25	547.69		
	17-Aug-02	1250	530.85	607.53	806.97		
16	18-Aug-02	1090	502.75	479.62	925.28		
	19-Aug-02	700	645.90	621.95	1069.04		
	20-Aug-02	2250	767.88	990.17	1630.37		
	21-Aug-02	180	357.76	431.90	716.51		
	22-Aug-02	120	274.25	267.36	423.34	350	390
	23-Aug-02	390	207.84	276.08	344.68		
	24-Aug-02	780	177.72	240.34	262.69		
17	25-Aug-02	1800	189.23	229.85	254.50		
	26-Aug-02	150	179.95	254.57	276.00		
	27-Aug-02	40	144.45	160.62	234.68		
	28-Aug-02	40	115.96	95.44	112.79		
	29-Aug-02	230	87.88	59.08	72.68	1840	3150
	30-Aug-02	540	68.84	35.94	42.08		
	31-Aug-02	460	103.58	28.25	35.04		
18	02-Sep-02	680	155.67	65.50	61.75		
	04-Sep-02	140	183.08	96.67	81.48		
	05-Sep-02	220	172.84	111.04	131.62	430	600
19	09-Sep-02	30	115.01	74.21	81.48		
	12-Sep-02	50	64.52	82.20	70.93	320	340
	16-Sep-02	170	39.59	46.78	53.75		

Individual stations exceeding 1,000 colonies/100-ml happened five times during 16 August through 25 August. A count of 6,100 colonies/100-ml resulted from the sample collected on 16 August at station SB3. This was the highest count of the five. The others ranged from 1090 to 2250 colonies/100-ml.

Escherichia coli (E. coli) was monitored at the swimming beach again this year to better understand bacteria trends. E. coli is the most reliable indicator of fecal bacterial contamination of surface waters in the United States according to water quality standards set by the EPA (2000). The EPA recommended recreational water quality standard for

E. coli is based on two criteria: geometric mean of 126 organisms/ 100 ml (geometric mean) threshold and 235 organisms/ 100 ml (single water sample) threshold.

E. coli contamination was consistently high at the swimming beach area of Blue Marsh Reservoir during 2002 (Table 3-16; Figs. 3-40 and 3-41). The geometric means calculated for each of the 3 surface water stations exceeded the water quality standard several times during the middle of the summer. The highest geometric means of E. coli were calculated for swimming beach station SB3 on 20 August at 786 clns/100-ml. There were two really high individual counts of 3900 on 16 August and 2070 on 20 August colonies/100-ml that exceeded EPA guidelines of 235 colonies/100-ml.

Table 3-16. Maximum counts of *Escherichita coli* and 5-day running geometric means of the 3 swimming beach stations of the Blue Marsh Reservoir.

Week	Date	Maximum Count	5-Day Geometric Means		
			sb1	sb2	sb3
1	09-May-02	70			
	13-May-02	110			
2	16-May-02	100			
	20-May-02	280			
3	23-May-02	30	75.91	27.87	26.31
	28-May-02	100	87.19	34.71	28.25
4	30-May-02	10	55.02	30.22	28.25
	03-Jun-02	40	43.24	30.22	37.28
5	06-Jun-02	270	33.66	39.59	24.02
	10-Jun-02	740	33.66	75.15	20.91
6	13-Jun-02	110	29.30	69.30	21.32
	17-Jun-02	180	45.47	109.83	38.00
7	20-Jun-02	90	41.93	136.82	44.69
	24-Jun-02	50	31.78	88.17	61.66
8	27-Jun-02	210	45.47	61.28	113.35
	01-Jul-02	80	48.16	64.07	106.36
9	03-Jul-02	10	31.04	40.43	59.66
	08-Jul-02	160	47.04	46.44	62.11
10	11-Jul-02	200	74.56	53.35	64.41
	15-Jul-02	70	41.83	47.89	50.14
11	18-Jul-02	460	31.70	68.07	71.14
	22-Jul-02	90	31.70	84.80	110.39
12	25-Jul-02	950	45.26	87.45	134.01
	29-Jul-02	320	49.72	119.85	187.30
13	01-Aug-02	110	65.61	126.03	211.44

Table 3-16. (Continued)					
			5-Day Geometric Means		
Week	Date	Maximum Count	sb1	sb2	sb3
14	05-Aug-02	790	103.99	137.60	235.59
	08-Aug-02	60	148.80	152.40	217.24
15	12-Aug-02	150	85.65	103.27	190.41
	13-Aug-02	530	86.69	116.51	175.02
	14-Aug-02	370	109.73	136.68	223.08
	15-Aug-02	50	95.53	73.33	122.84
	16-Aug-02	3900	220.15	156.30	278.60
	17-Aug-02	840	341.64	316.41	393.20
16	18-Aug-02	290	330.94	211.07	381.26
	19-Aug-02	690	300.32	270.38	391.05
	20-Aug-02	2070	388.01	683.86	785.73
	21-Aug-02	90	135.16	306.83	375.72
	22-Aug-02	80	80.31	199.99	228.57
	23-Aug-02	170	62.07	218.91	225.98
	24-Aug-02	190	66.16	138.52	192.82
17	25-Aug-02	160	56.25	83.01	117.49
	26-Aug-02	350	91.68	121.62	154.15
	27-Aug-02	40	91.68	80.24	130.12
	28-Aug-02	10	60.49	49.67	73.84
	29-Aug-02	10	37.44	33.66	40.97
	30-Aug-02	260	47.40	29.30	42.37
	31-Aug-02	260	48.57	20.91	31.54
18	02-Sep-02	430	78.11	48.19	59.38
	04-Sep-02	710	115.27	74.79	78.36
	05-Sep-02	90	143.59	74.79	136.43
19	09-Sep-02	160	74.84	56.68	81.68
	12-Sep-02	20	44.81	51.18	53.89
20	16-Sep-02	30	26.31	22.21	22.97

Blue Marsh Reservoir personnel collected precipitation data near the dam during 2002. Data collected from May to October (Fig. 2-2 through Fig. 2-6) were used to qualitatively correlate rainfall in the immediate vicinity of the swimming beach with coliform bacteria levels. Swimming beach coliform levels did not appear to correlate strongly with precipitation data. High and low counts were interspersed with increased precipitation and flow. Rainfall values for the region were; however, at historical lows for the area. Throughout the monitoring period, the monthly precipitation averaged 2.6 inches; while, precipitation in July was only 0.48 inches. This may account for the high bacteria levels observed at the swimming beach in 2002. To further determine if a relationship exists between precipitation and coliform bacteria levels at the swimming beach future monitoring plans should prioritize sampling directly following precipitation events.

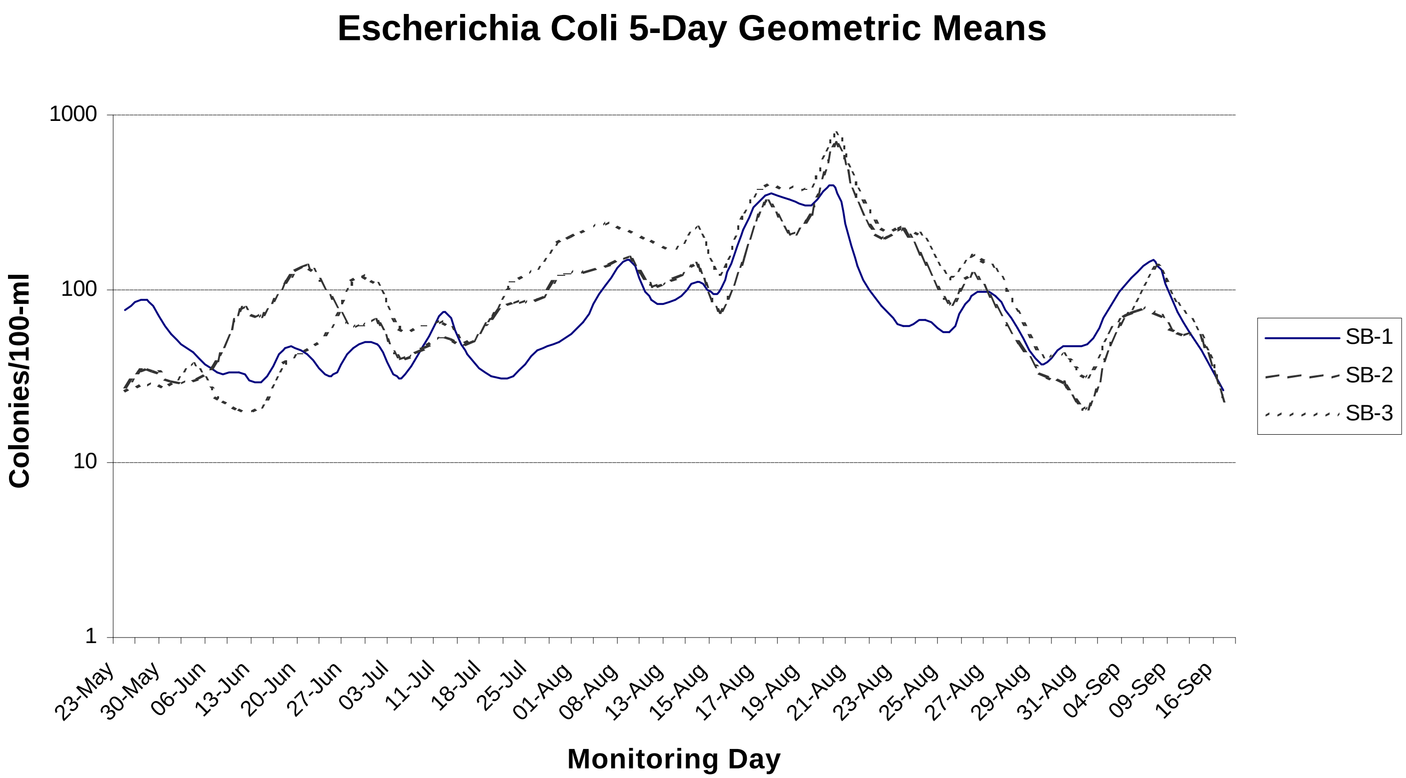

Figure 3-40. Five day geometric means for *Escherichia coli* from May until September 2002 at Blue Marsh Reservoir

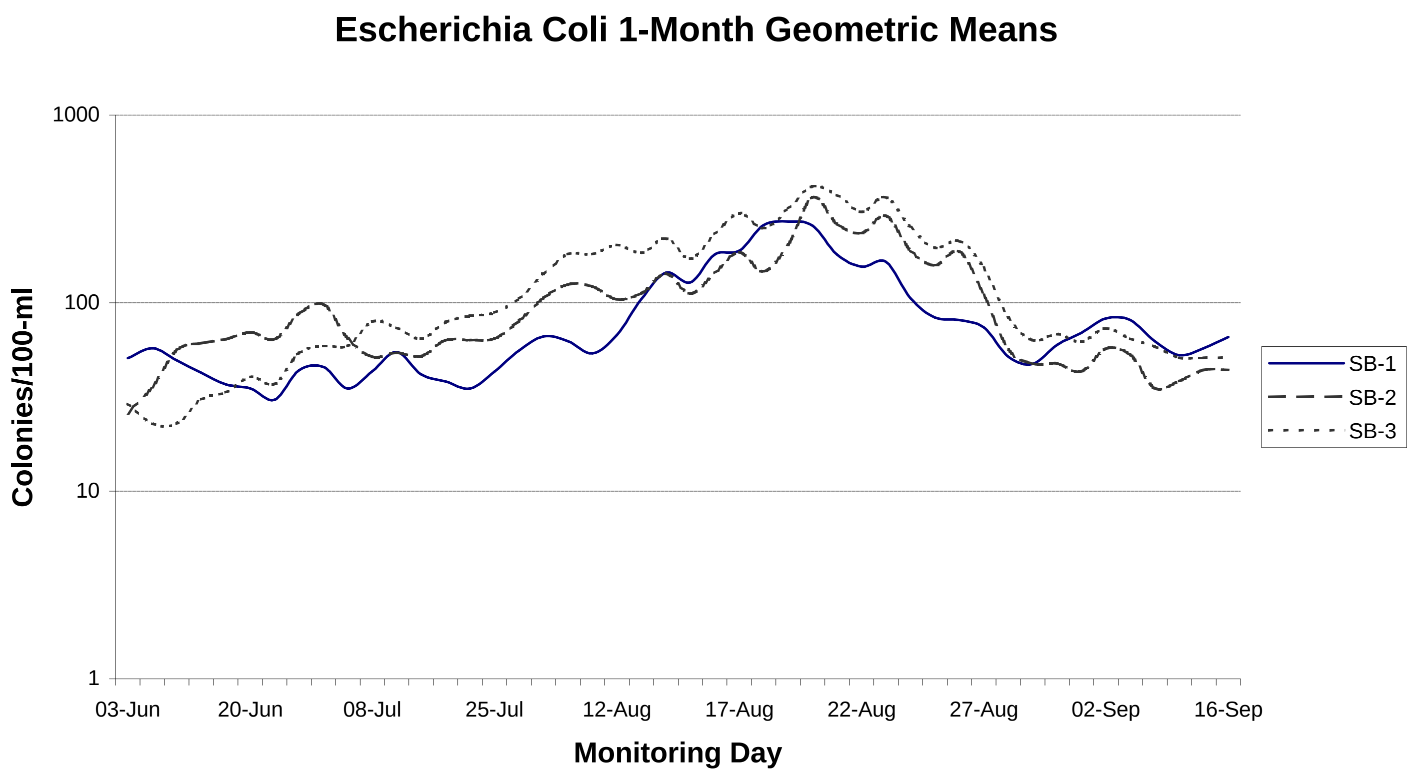

Figure 3-41. One-month geometric means for *Escherichia coli* from June until September 2002 at Blue Marsh Reservoir

3.5.2 Weekly Monitoring at Stations BM-11 and BM-12

Coliform bacteria contamination was consistently high at stations BM-11 and BM-12 (Table 3-15). Fecal coliform counts exceeded the PADEP water quality standard of 200 colonies/100-ml in 19 of 20 weeks of monitoring at station BM-11. Overall, counts ranged from 120 to 7,600 colonies/100-ml and averaged 1278 colonies/100-ml. In Previous years bacteria contamination at station BM-11 was attributed to the Bernville wastewater management facility located immediately upstream on Tulpehocken Creek. However, fecal coliform counts exceeded the PADEP water quality standard of 200 colonies/100-ml in 18 of 20 weeks of monitoring at station BM-12, just upstream of the wastewater facility. Overall, counts ranged from < 10 to 5,800 colonies/100-ml and averaged 1241 colonies/ 100-ml. Further investigation of upstream activities may be warranted to determine the source of the coliform contamination.

3.6 SEDIMENT PRIORITY POLLUTANT MONITORING

Sediment samples were collected at stations BM-2 and BM-6 and analyzed for priority pollutant contaminants, Group 1 – PCB's, pesticides and volatile organic compounds. Resulting concentrations were compared to New Jersey Soil Cleanup Criteria (NJDEP 1999). The NJDEP criteria are human health based with categories addressing residential and non-residential settings, and impacts to groundwater. For our comparison, we reported the most conservative of the two criteria.

There was only one parameter (delta BHC) that was detected of the 93 priority pollutant contaminants analyzed from Blue Marsh Reservoir sediments (Table 3-17). The pesticide delta-BHC was found at station BM-6 with a value of 1812 ppb. Delta-BHC is also known as delta-Hexachlorocyclohexane. Accoding to the EPA's Integrated Risk Information System no data exists at this time linking this substance as a human or animal carcinogen (EPA 2002).

3.7 ARSENIC MONITORING

Arsenic monitoring was conducted in the deep section of Blue Marsh Reservoir near the "Tower" (station BM-6) and "Spillway" (station BM-2). Monitoring was conducted on 22 July and 1 October during the peak summer temperature stratification. Arsenic and iron concentrations were measured in sediments and in water for total and dissolved constituents. Iron was included in the analyses because it has a chemical reactivity similar to arsenic, and thus might aid in the interpretation of results.

Arsenic was not detected in the bottom waters or sediments of Blue Marsh Reservoir during 2002 (Table 3-18). The concentrations of iron measured in the sediment at BM-2 and BM-6 in the 22 July collections were 12,416 and 13,715 mg/kg. While concentrations for 1 October collection were 125 and 117 mg/kg, respectively. Iron concentrations have exhibited no discernible pattern over the past 18 years of water quality monitoring at Blue Marsh Reservoir. Regression analyses conducted did not result in any significant trends (Figs. 3-42 and 3-43). Average TDS concentrations calculated this year were of the same order as in prior years.

Table 3-17. Priority pollutant contaminant concentrations, Group 1 –volatile organic compounds, PCB's, and pesticides measured in sediments of Blue Marsh Reservoir during August 2002 (all concentrations reported are based on dry weight).

	Residential Direct Contact Soil Cleanup Criteria	Non-Residential Direct Contact Soil Cleanup Criteria	Units	Method Detection Limit	BM-6	BM-2
PCBs - Method 8082						
Aroclor-1016			ppb	100	ND	ND
Aroclor-1221			ppb	100	ND	ND
Aroclor-1232			ppb	100	ND	ND
Aroclor-1242			ppb	100	ND	ND
Aroclor-1248			ppb	100	ND	ND
Aroclor-1254			ppb	100	ND	ND
Aroclor-1260			ppb	100	ND	ND
Pesticides - Method 8081A						
4,4'-DDD	3000	12000	ppb	4	ND	ND
4,4'-DDE	2000	9000	ppb	4	ND	ND
4,4'-DDT	2000	9000	ppb	4	ND	ND
alpha-BHC			ppb	4	ND	ND
a-Chlordane			ppb	4	ND	ND
Aldrin	40	170	ppb	4	ND	ND
beta-BHC			ppb	4	ND	ND
Chlordane, technical			ppb	40	ND	ND
delta-BHC			ppb	4	1812	ND
Dieldrin	42	180	ppb	4	ND	ND
Endosulfan I	340000	6200000	ppb	4	ND	ND
Endosulfan II	340000	6200000	ppb	4	ND	ND
Endrin	17000	310000	ppb	4	ND	ND
Endrin aldehyde			ppb	4	ND	ND
Endrin ketone			ppb	4	ND	ND
Endosulfan Sulfate			ppb	4	ND	ND
gamma-BHC (Lindane)	520	2200	ppb	4	ND	ND
g-Chlordane			ppb	4	ND	ND
Heptachlor	150	650	ppb	4	ND	ND
Heptachlor epoxide			ppb	4	ND	ND
Methoxychlor	280000	5200000	ppb	10	ND	ND
Toxaphene	100	200	ppb	200	ND	ND

Table 3-17. (Continued).						
	Residential Direct Contact Soil Cleanup Criteria	Non-Residential Direct Contact Soil Cleanup	Units	Method Detection Limit	BM-6	BM-2
Volatile Organic Compounds - Method 8260B						
1,1,1,2-Tetrachloroethane	170000	310000	ppb	1	ND	ND
1,1,1-Trichloroethane	210000	1000000	ppb	1	ND	ND
1,1,2,2-Tetrachloroethane	34000	70000	ppb	1	ND	ND
1,1,2-Trichloroethane	22000	420000	ppb	1	ND	ND
1,1-Dichloroethane	570000	1000000	ppb	1	ND	ND
1,1-Dichloroethene	8000	150000	ppb	1	ND	ND
1,1-Dichloropropene			ppb	1	ND	ND
1,2,3-Trichlorobenzene			ppb	1	ND	ND
1,2,3-Trichloropropane			ppb	1	ND	ND
1,2,4-Trichlorobenzene	68000	1200000	ppb	1	ND	ND
1,2,4-Trimethylbenzene			ppb	1	ND	ND
1,2-Dibromo-3-chloropropane			ppb	1	ND	ND
1,2-Dichloroethane	6000	24000	ppb	1	ND	ND
1,2-Dichlorobenzene	5100000	10000000	ppb	1	ND	ND
1,2-Dichloropropane	10000	43000	ppb	1	ND	ND
1,2-Dibromoethane			ppb	1	ND	ND
1,3,5-Trimethylbenzene			ppb	1	ND	ND
1,3-Dichlorobenzene	5100000	10000000	ppb	1	ND	ND
1,3-Dichloropropane			ppb	1	ND	ND
1,4-Dichlorobenzene	570000	10000000	ppb	1	ND	ND
2,2-Dichloropropane			ppb	1	ND	ND
2-Chlorotoluene			ppb	1	ND	ND
2-Hexanone			ppb	10	ND	ND
4-Chlorotoluene			ppb	1	ND	ND
Acetone	1000000	1000000	ppb	10	ND	ND
Benzene	3000	13000	ppb	1	ND	ND
Bromochloromethane			ppb	1	ND	ND
Bromodichloromethane	11000	46000	ppb	1	ND	ND
Bromobenzene			ppb	1	ND	ND
Bromoform	86000	370000	ppb	1	ND	ND
Bromomethane	79000	1000000	ppb	1	ND	ND
c-1,2-Dichloroethene	79000	1000000	ppb	1	ND	ND
c-1,3-Dichloropropene	4000	5000	ppb	1	ND	ND
Carbon Tetrachloride	2000	4000	ppb	1	ND	ND
Chlorobenzene	37000	680000	ppb	1	ND	ND
Chloroethane			ppb	1	ND	ND
Chloroform	19000	28000	ppb	1	ND	ND
Chloromethane	520000	1000000	ppb	1	ND	ND
Methylene Chloride (DCM)	49000	210000	ppb	1	ND	ND

Table 3-17. (Continued).						
	Residential Direct Contact Soil Cleanup Criteria	Non-Residential Direct Contact Soil Cleanup	Units	Method Detection Limit	BM-6	BM-2
Volatile Organic Compounds - Method 8260B (Con't)						
Dibromochloromethane	110000	1000000	ppb	1	ND	ND
Dibromomethane			ppb	1	ND	ND
Dichlorofluoromethane			ppb	1	ND	ND
Ethylbenzene	1000000	1000000	ppb	1	ND	ND
Hexachloro1,3-butadiene	1000	21000	ppb	1	ND	ND
Isopropylbenzene (cumene)			ppb	1	ND	ND
m,p-Xylene			ppb	1	ND	ND
2-Butanone(MEK)	1000000	1000000	ppb	10	ND	ND
4-Methyl-2-pentanone (MIBK)	1000000	1000000	ppb	10	ND	ND
Methyl-tert-butylether (MTBE)			ppb	1	ND	ND
n-ButylBenzene			ppb	1	ND	ND
n-Propylbenzene			ppb	1	ND	ND
Naphthalene	230000	4200000	ppb	1	ND	ND
o-Xylene			ppb	1	ND	ND
p-Isopropyltoluene			ppb	1	ND	ND
Tetrachloroethene	4000	6000	ppb	1	ND	ND
sec-Butylbenzene			ppb	1	ND	ND
Styrene	23000	97000	ppb	1	ND	ND
trans-1,2-dichloroethene	1000000	1000000	ppb	1	ND	ND
t-1,3-Dichloropropene	4000	5000	ppb	1	ND	ND
t-Butylalcohol			ppb	10	ND	ND
Trichloroethene	23000	54000	ppb	1	ND	ND
Toluene	1000000	1000000	ppb	1	ND	ND
Trichlorofluoromethane			ppb	1	ND	ND
Vinyl chloride	2000	7000	ppb	1	ND	ND

Arsenic data collected over the past 20 years were analyzed for trends using regression methods. Regression analyses was not conducted on total and dissolved arsenic or arsenic in the sediment because all concentrations in the water and sediment over the last two years to levels below the laboratory method detection limits.

Dissolved iron concentrations were all below the detection limit of 0.002 mg/L. Total iron concentrations in the lower water column of Blue Marsh Reservoir were slightly greater in July than in October. No significant trends were observed for total and dissolved iron in water (Fig 3-43).

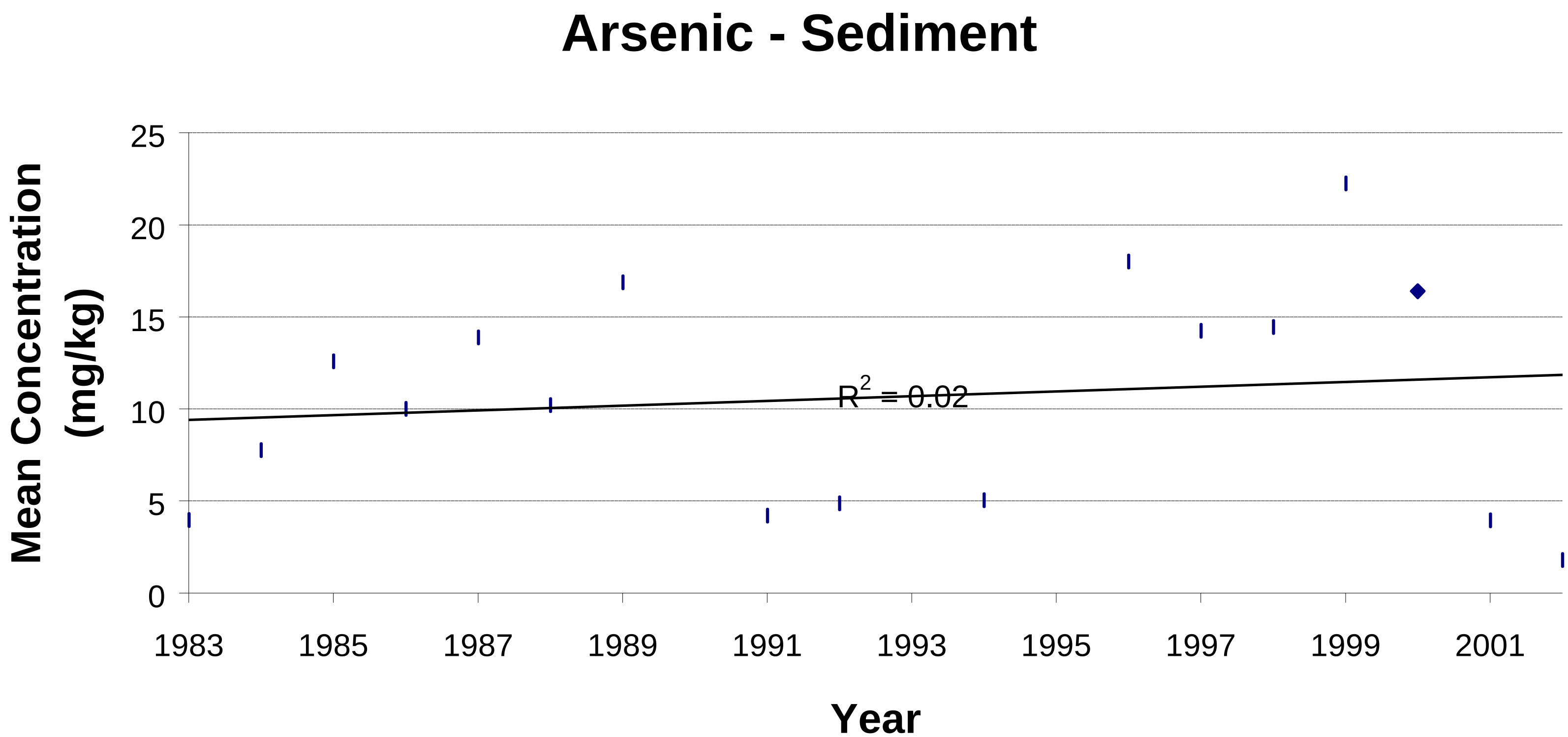

Figure 3-42. Trends for arsenic in the sediment of Blue Marsh Reservoir

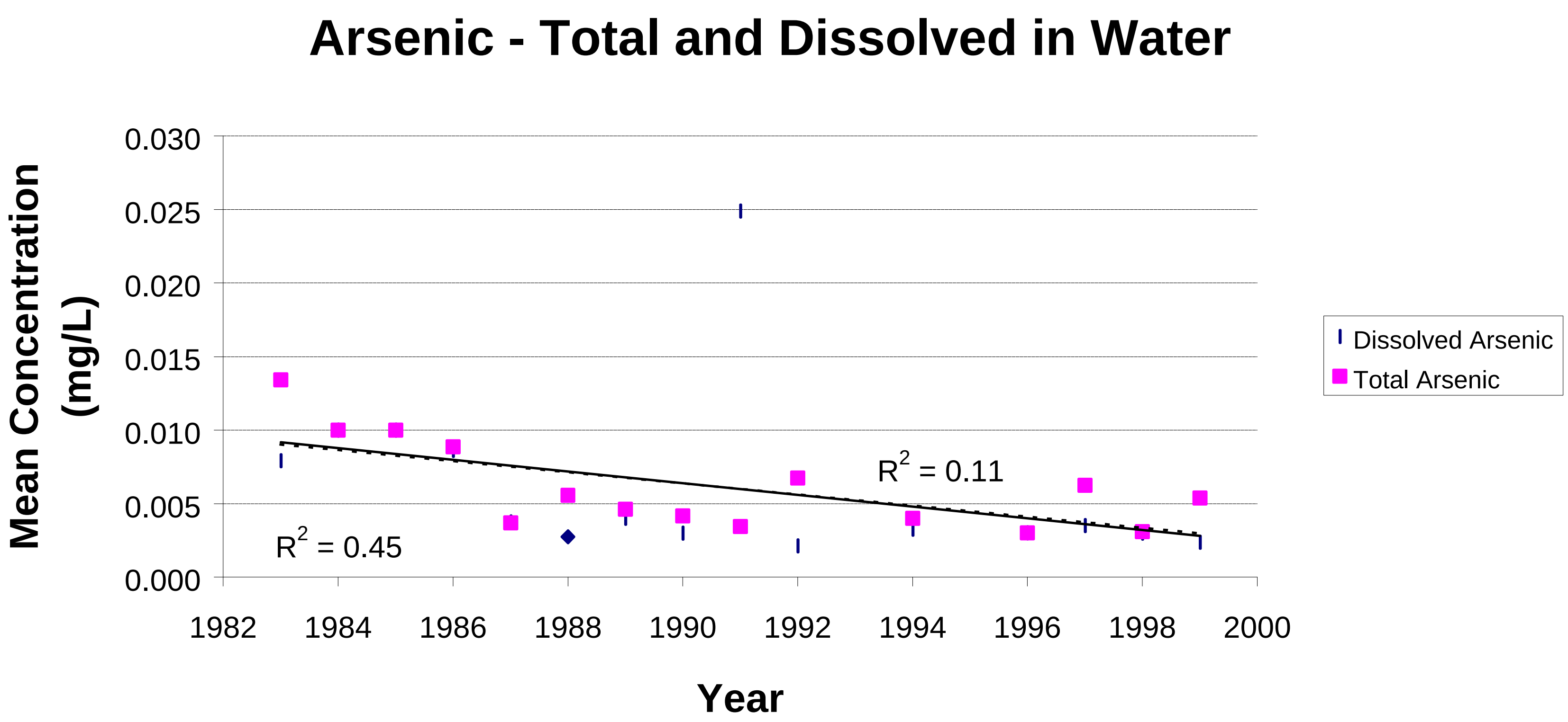

Figure 3-43. Trends for total and dissolved iron in bottom waters of Blue Marsh Reservoir

Table 3-18. Arsenic and iron in bottom sediments and the lower water column of Blue Marsh Reservoir during 2002

Station	BM-2		BM-6	
Sampling date	22 July	1 October	22 July	1 October
Sediment (mg/kg)				
Total Arsenic	< 3.047	< 0.231	< 3.607	< 0.231
Total Iron	12,416	1,252	13,715	1,178
Bottom Water (mg/L)				
Total Arsenic	< 0.01	< 0.01	< 0.01	< 0.01
Dissolved Arsenic	< 0.01	< 0.01	< 0.01	< 0.01
Total Iron	1.294	0.534	0.597	0.270
Dissolved Iron	< 0.002	< 0.002	< 0.002	< 0.002

3.8 DRINKING WATER

Drinking water from the public water fountain located in the overlook building of Blue Marsh Reservoir was monitored for compliance with PADEP water quality standards for primary and secondary contaminants, and quarterly monitored for inorganic nitrogen (nitrate and nitrite) and coliform bacteria contaminants during 2002. Drinking water samples were analyzed in duplicate, comprising initial and confirmation samples. For matters of reporting, only if the result of the initial sample was not in compliance with water quality standards is the result of the confirmation sample was also reported.

3.8.1 Primary and Secondary Contaminants

Blue Marsh Reservoir drinking water was in compliance with PADEP water quality standards for all the primary and secondary contaminants with the exception of lead and pH (Table 3-19). Lead is a primary drinking water contaminant with a maximum contaminant level (MCL) of 0.015 mg/L. In August, lead exceeded this level both in the initial and secondary sample. The initial sample was 0.024 mg/L and the secondary sample was 0.03 mg/L. Another primary drinking water contaminant that exceeded the regulatory level was iron. The regulatory level of iron was 0.3 mg/L and the initial sample measured 0.471 mg/L and the secondary sample measured 0.371 mg/L. Regulatory level of pH is 6.5-8.5, which is a secondary drinking water contaminant. Again in the August, sampling pH was less than the regulatory level. The initial pH level was 6.38 and the secondary level was 6.36. As part of drinking water compliance monitoring, Safe Drinking

Water Act (SDWA) form 4 for the reporting of results of primary and secondary drinking water contaminants were submitted to appropriate state environmental agencies.

Table 3-19. Concentrations of primary and secondary contaminants in drinking water at Blue Marsh Reservoir in 2002. Shaded values indicate results that exceeded Pennsylvania State drinking water standards; in these instances the result of a second sample is also reported.

Parameter	Sampling Date		PADEP Regulatory Level	Detection Limits	EPA Method
	13 March	19 August			
Aluminum	ND	ND	0.2	0.025	200.7
Antimony	ND	ND	0.006	0.024	200.7
Arsenic	ND	ND	0.05	0.018	200.7
Barium	0.013	0.012	2.0	0.005	200.7
Cadmium	ND	0.001	0.005	0.001	200.7
Chromium	ND	0.002	0.1	0.006	200.7
Copper	0.274	0.486	1.3	0.002	200.7
Iron	0.063	0.471/0.371	0.3	0.005	200.7
Lead	ND	0.024/0.03	0.015	0.01	200.7
Magnesium	13.33	13.542	NL	0.02	200.7
Manganese	0.018	0.02	0.05	0.002	200.7
Mercury	0.001	ND	0.002	0.0002	245.1
Nickel	ND	0.003	0.1	0.003	200.7
Selenium	ND	ND	0.05	0.02	200.7
Silver	ND	ND	0.1	0.003	200.7
Sodium	1.612	1.256	NL	0.02	200.7
Thallium	ND	ND	0.002	0.063	200.7
Zinc	0.119	0.137	5.0	0.003	200.7
Chloride	11.7	14	250	0.5	300
Cyanide, free	ND	ND	0.2	0.009	SM 4500CN-I
Fluoride	ND	ND	2.0	0.1	300
Foaming Agents	ND	ND	0.5	0.01	SM 5540C
PH	6.69	6.38/6.36	6.5-8.5	+/-0.01	150.1
Sulfate	3.8	5	250.0	5	300
Total Dissolved Solids	170	116	500.0	10	160.1

All results, criteria and detection limits are expressed in mg/L except pH which is expressed in positive/negative
ND –Not Detected
NL –Not Listed

3.8.2 Inorganic Nitrogen and Coliform Bacteria

Blue Marsh Reservoir drinking water was in compliance with PADEP criteria for inorganic nitrogen contaminants, nitrate and nitrite, and coliform bacteria contaminants (Table 3-20). Concentrations of nitrate ranged from 2.1 to 4.0 mg/L. Nitrite was detected only once in June with a value of 0.6 mg/L which does not exceed the PADEP regulatory level. All of the tests for *E. co*li and total coliform resulted in the absence coliform contaminants. Following laboratory testing, drinking water monitoring results were recorded on Safe Drinking Water Act (SDWA-S and SDWA-4) forms and submitted to the appropriate state environmental agencies.

3.8.3 Historical Drinking Water Quality

Drinking water quality has been monitored at Blue Marsh Reservoir over the past 20 years. Versar (1996) compiled the results from all of the previous years into a single database to facilitate water quality comparisons. Historical data from drinking water quality parameters were compared to their respective PADEP standards. Of 26 parameters summarized, 7 had incidences of noncompliance with drinking water standards from 1983 to present (Table 3-21). Lead, pH, and corrosivity were most often not in compliance with PADEP criteria; lead, iron and pH were the parameters slightly out of compliance during the 2002 monitoring.

Table 3-20. Concentrations of nitrate and nitrite, and results of coliform bacteria monitoring of drinking water sampled from the public water fountain located in the overlook building at Blue Marsh Reservoir during 2002

Parameter	Sampling Dates				PADEP Regulatory Level	Detection Limits	Method
	13 March	18 June	19 August	10 October			
Nitrate as N (mg/L)	2.1	2.6	3.96	2.93	10.0	0.5	300
Nitrite as N (mg/L)	ND	0.6	ND	ND	1.0	0.5	300
E. coli (CFU)	Absence	Absence	Absence	Absence	Presence	10	SM 9223
Total Coliform (CFU)	Absence	Absence	Absence	Absence	Presence	10	SM 9223

CFU –colony forming units
ND –Not Detected

Table 3-21. A chronology of Blue Marsh Reservoir drinking water parameters that have not complied with PADEP water quality standards from 1983 to 2002

Parameter	Monitoring Date	Result	Criteria
Arsenic (mg/L)	21 August 1991	0.160	0.005
Iron (mg/L)	31 May 1989	0.56	0.3
	21 August 2002	0.371	0.471
Lead (mg/L)	17 August 1984	0.1	0.015
	11 July 1988	0.038	0.015
	23 April 1990	0.017	0.015
	22 August 1995	0.017	0.015
	12 June 1996	0.017	0.015
	21 August 1996	0.024	0.015
	8 June 1998	0.016	0.015
	12 June 2001	0.015	0.015
	19 August 2002	0.03	0.015
PH	27 April 1983	6.3	6.5-8.5
	11 July 1988	5.83	6.5-8.5
	23 April 1990	6.05	6.5-8.5
	15 June 1992	6.41	6.5-8.5
	1 June 1993	6.38	6.5-8.5
	7 September 1993	6.33	6.5-8.5
	24 May 1994	6.41	6.5-8.5
	21 August 1996	6.24	6.5-8.5
	8 June 1998	6.14	6.5-8.5
	19 August 2002	6.36	6.5-8.5
Corrosivity	12 June 1996	-1.21	Non-negative
	21 August 1996	-1.8	Non-negative
	16 June 1997	-1.34	Non-negative
	20 August 1997	-1.33	Non-negative
	8 June 1998	-1.66	Non-negative
	23 June 1999	NEG	Non-negative
	18 August 1999	NEG	Non-negative
	19 June 2000	-3	Non-negative
Fecal coliform (colonies/100-mls)	11 July 1988	90	Absence
	7 July 1991	7	Absence
Total coliform (colonies/100-mls)	11 July 1988	10500	Absence
	10 March 1992	1	Absence

4.0 SUMMARY

The USACE implements a yearly monitoring program at Blue Marsh Reservoir to monitor water quality and to evaluate potential public health concerns. In general, the monitoring programs emphasize measuring water quality and sediment contamination. Monitoring results are compared to state and federal criteria to evaluate the condition of Blue Marsh Reservoir. The 2002 monitoring program of Blue Marsh Reservoir comprised six major elements:

- monthly stratification monitoring of physical/chemical water quality conditions at fixed stations from May through October;
- monthly water quality monitoring of nutrient, organic, and inorganic contaminants, and coliform bacteria levels at fixed stations from May through October;
- semi-weekly coliform bacteria monitoring at the public swimming beach and weekly monitoring up and downstream of the Bernville wastewater treatment facility located on the Northkill Creek;
- sediment priority pollutant monitoring for volatile organic compounds, PCB's and pesticides at two fixed stations;
- sediment and bottom water arsenic monitoring for potential contaminants originating from an upstream hazardous waste site; and
- drinking water monitoring of the public water fountain in the overlook building.

4.1 WATER QUALITY MONITORING

Surface and downstream water quality were not in compliance with state standards for dissolved oxygen concentrations (minimum of 5 mg/L). Dissolved oxygen in the lower water column of the deeper portions of the reservoir was usually below standards throughout the monitoring period as well as surface stations BM-2 and BM-6 in October. Measures of pH and ammonia throughout the water column of the reservoir generally met the conditions of the water quality standard. Measures of pH and ammonia exceed the standard on three occasions between July and August. Concentrations of nitrate and nitrite were primarily in compliance with PADEP water quality standards during 2002, with the exception of BM-7 and BM-8 in August. The state water quality standard for nitrogen from nitrite and nitrate sources is a summed concentration of not more than 10 mg/L. Measures for total phosphorus with results greater than the detection limit exceed the EPA guideline in 95% of the samples. TDS, and alkalinity were in compliance with state water quality standards throughout the reservoir watershed. Organic contamination in the reservoir was relatively low during 2002. Concentrations of benzene, toluene, o-xylene and m,p-xylenes were rarely measured above detection limits throughout the monitoring period.

The trophic status of Blue Marsh Reservoir was defined independently by Carlson's trophic state indices and EPA criteria. Both methods of trophic classification were based on concentrations of total phosphorus and chlorophyll *a*, and measures of secchi disk depth. Overall, both classifications indicated borderline mesoeutrophic/eutrophic conditions dominated in the reservoir during 2002.

Blue Marsh Reservoir was in compliance with PADEP water quality standards for bacteria during 2002. The geometric means among samples collected each month were always less than the water quality standard, a maximum fecal coliform density of 200-clns/100-ml. Elevated coliform bacteria counts were routinely observed upstream of the reservoir on Tulpehocken and Northkill Creeks. Previously, it was thought that the water quality at station BM-5 was most likely influenced by discharges from the Bernville Wastewater Management Facility; however, station BM-11, located just below and station BM-12 located just above the treatment facility, both had higher than average concentrations fecal coliform.

The public swimming beach of the Dry Brooks day use area of Blue Marsh Reservoir was not in compliance with Pennsylvania Department of Health bathing beach water quality standards. Individual readings of 1000 colonies/100-ml or geometric means of fecal coliform exceeded 200 colnies/100-ml at one or more of the swimming beach stations on 16 days during July and August. Additionally, E. coli exceeded individual readings of 235 organisms/100-ml or geometric means of 126 organisms/100-ml at one or more of the swimming beach stations on 29 days throughout the monitoring period.

4.2 SEDIMENT PRIORITY POLLUTANT MONITORING

Sediment priority pollutant monitoring was conducted at two stations in the deepest part of the reservoir. A total of 93 priority pollutant contaminants comprising of PCB's, pesticides and volatile organic compounds were assayed in bottom sediments. None of the priority pollutant contaminants exceeded the screening levels.

4.3 ARSENIC MONITORING

Monitoring of arsenic in sediments and bottom water suggested that small amounts of arsenic might be mobilizing from sediments to the water column during periods of anoxia. However sediment concentrations from most samples were less than USACE screening level (20 mg/kg), and concentrations of total and dissolved arsenic in bottom water were less than the PADEP water quality criteria for dissolved trivalent arsenic (0.19 mg/L).

4.4 MONITORING PROGRAM TRENDS

Analysis of long-term trends suggested that significant water quality changes have occurred in Blue Marsh Reservoir over the past 22 years. Regression analysis for total phosphorus and fecal coliform data indicated that average concentrations have significantly decreased since the 1980s.

Trends computed for individual stations using the Mann-Kendall test indicated significant water quality changes at several locations in the Blue Marsh Reservoir drainage. Spring and Licking Creeks both had decreasing trends for total nitrogen, total phosphorus, total dissolved solids, and total coliform. Trends for Tulpehocken Creek, the primary up-stream source included decreasing total phosphorus, but also increasing fecal coliform. Trends within the reservoir were also mixed as to overall effect on ecological health. At station BM-2, ammonia and TDS were increasing, while total phosphorus was decreasing. At BM-6, fecal coliform was increasing. Total phosphorus was decreasing and fecal coli-form was increasing at station BM-9. Downstream trends by the Mann-Kendall test included decreasing ammonia and total phosphorus and increasing fecal coliform.

4.5 DRINKING WATER MONITORING

Drinking water from the public fountain located in the overlook building of Blue Marsh Reservoir was in compliance with most water quality standards in 2002. Of the primary and secondary contaminants, lead and pH exceeded the PADEP criteria for both initial and confirmation samples. An evaluation of drinking water monitoring criteria from 1983 to present has confirmed that detections of lead and pH have occurred in the past years for this drinking water source. All drinking water samples were in compliance with water quality standards for nitrate/nitrite and coliform bacteria contamination.

5.0 RECOMMENDATIONS

The USACE intends to continue monitoring Blue Marsh Reservoir in future years to evaluate trends and to identify potential environmental problems related to human development within the watershed. The USACE is continually seeking to improve the quality and cost-effectiveness of the information gathered as part of this effort. Below, we present recommendations for improving the monitoring program and water quality in the reservoir:

Recommendation 1: Continue the semi-weekly sampling of coliform bacteria at the swimming beach

In 1999, monitoring of the Blue Marsh Reservoir swimming beach was altered to include semi-weekly sampling of three fixed swimming beach stations. The monitoring design was implemented in 2001 as well and was able to provide quick turnaround results to support reservoir management decisions with regards to public use. We recommend continuing with this monitoring design as it provides accurate as well as time sensitive estimates of coliform contaminants. Furthermore, sampling twice a week enables the Corps to calculate the geometric mean between two separate sampling events that is more consistent with current state regulatory requirements for swimming beaches.

Recommendation 2: Additional sampling further upstream of Blue Marsh Reservoir to determine source of increased concentrations of bacteria and nutrients

The water quality monitoring data at Blue Marsh reservoir as well as additional water quality monitoring above and below the Bernville plant located in the headwaters of the reservoir data on Northkill Creek suggests that high concentrations of bacteria, alkalinity, nitrate, TDS, TSS, and total phosphorus may not be the direct result of discharges from Bernville plant. Coliform concentrations recorded above the plant were comparable to or higher than those recorded below the plant. In addition, concentrations of alkalinity, nitrate, TDS, TSS, and total phosphorus recorded below the confluence of Tuplehoken Creek were higher than those recorded on Northkill Creek. Additional sampling further upstream of Blue Marsh Reservoir is needed to better determine the source(s) of increased concentrations of bacteria and nutrients.

Recommendation 3: Promote watershed Best Management Practices (BMP) designed to reduce non-point source inputs of nutrients into the reservoir

The Berks County Conservancy, state and local agencies has made great strides in assisting local farmers install BMP in the watershed. These controls include installing manure pits for cattle feed lots, stream exclusion devices for live stock, erosion control measures for field and construction sites, buffer strips around streams, and other technologies designed to reduce non-point inputs of nutrients and sediments. As more improvements in the management of agricultural lands are accomplished within the watershed, Blue Marsh Reservoir water quality will also improve. Wherever possible, the USACE should identify, encourage, and promote these watershed improvement projects.

Recommendation 4: Investigate the feasibility of instituting stable reservoir water level to promote the establishment of a littoral zone

Local researchers from Albright College, state agencies, and environmental groups have suggested that the USACE should consider establishing a stable reservoir level to help promote the growth and establishment of submerged aquatic vegetation around the perimeter of the reservoir. Establishment of a "littoral zone" would improve water quality (by removal of nutrients through plant growth) and would improve the aquatic habitat by providing food, and refuge for fish. However, because the reservoir was constructed primarily for flood control, changes in the operation of the facility cannot be considered without and extensive study and evaluation of the proposed change. If sufficient cost sharing and initiatives are forthcoming from authorized state resource agencies, the USACE should conduct a feasibility study on the proposed changes in reservoir operation. This feasibility study should include, but not limited to, food control modeling, engineering evaluations, estimations on the effect on downstream water use needs, and an assessment of potential ecological benefits of a stable reservoir level.

Recommendation 5: Drop arsenic sediment and water testing in the reservoir

Arsenic testing for the last six years have resulted in few detections in the sediment and water samples. This element was added to the program in response to a potential contaminant source in the watershed. The data indicate that harmful levels of arsenic do not occur in the reservoir bottom waters or the sediments. Since there does not appear to be a problem with arsenic, the sampling and analyses effort should be directed toward other water quality issues.

6.0 REFERENCES

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APPENDIX A

STRATIFICATION MONITORING

Table A-1. Summary of stratification monitoring at Blue Marsh Reservoir in 2002							
Station	**Date**	**Depth (F)**	**Temp ©**	**pH**	**DO (mg/L)**	**DO (%)**	**Cond (ms/cm)**
BM1	20-May	0	14.61	7.65	8.63	84.9	0.347
	18-Jun	0	21.59	7.84	8.81	100.1	0.348
	22-Jul	0	24.69	8.66	14.63	176.2	0.364
	19-Aug	0	21.83	7.74	9.83	112.2	0.379
	01-Oct	0	22.22	7.85	9.71	111.7	0.36
BM2	20-May	42	11.69	7.34	0.8	7.4	0.367
		40	12.53	7.25	1.5	14.1	0.356
		35	12.93	7.25	1.72	16.3	0.354
		30	13.7	7.27	2.21	21.3	0.35
		25	15	7.31	3.24	32.1	0.344
		20	15.75	7.47	5.03	50.7	0.341
		15	16.05	8.03	6.16	62.5	0.337
		10	16.66	8.2	7.16	73.6	0.332
		5	16.78	8.37	8.46	87.2	0.331
		0	16.97	8.43	8.88	91.9	0.332
	18-Jun	45	12.38	7.11	0	0	0.369
		40	12.68	7.06	0	0	0.365
		35	13.31	7.06	0	0	0.361
		30	14.03	7.1	1.01	9.8	0.356
		25	14.8	7.12	1.48	14.6	0.356
		20	17.12	7.14	1.55	16.1	0.373
		15	18.92	7.18	1.64	17.6	0.386
		10	22.37	7.91	6.53	75.3	0.343
		5	22.65	8.17	7.38	85.6	0.342
		0	23.87	8.24	7.44	88.3	0.343
	22-Jul	48	13.06	7.22	0	0	0.396
		45	13.4	7.21	0	0	0.393
		40	13.99	7.25	0	0	0.389
		35	14.69	7.28	0	0	0.388
		30	16.5	7.3	0	0	0.397
		25	19.16	7.32	0	0	0.41
		20	24.93	7.68	3.63	43.9	0.383
		15	25.95	7.52	1.34	16.6	0.363
		10	26.93	8.26	6.87	86.2	0.345
		5	27.83	8.56	7.99	101.9	0.336
		0	27.9	8.58	8.15	104.1	0.337
	19-Aug	44	15.05	7.29	0.9	8.9	0.418
		40	15.35	7.23	0.38	3.8	0.416
		35	16.88	7.25	0.13	1.3	0.414
		30	18.32	7.25	0	0	0.413
		25	21.39	7.28	0	0	0.405
		20	24.38	7.36	0	0	0.381
		15	25.8	7.43	0.14	1.7	0.357
		10	28.34	8.42	8.03	103.3	0.318
		5	28.66	8.62	9.41	121.7	0.311
		0	29.79	8.76	10.53	139	0.309

Table A-1. (Continued)

Station	Date	Depth (F)	Temp ©	pH	DO (mg/L)	DO (%)	Cond (ms/cm)
BM 2 (Continued)	01-Oct	45	19.15	7.32	1.17	12.6	0.387
		40	19.38	7.3	0.59	6.4	0.377
		35	19.61	7.31	1.03	11.3	0.37
		30	20.44	7.38	1.95	21.7	0.352
		25	20.79	7.41	2.3	25.8	0.349
		20	20.81	7.41	2.5	28	0.346
		15	20.92	7.42	2.49	28	0.344
		10	21.08	7.5	3.21	36.2	0.348
		5	21.61	7.57	4.12	46.8	0.346
		0	21.77	7.61	4.6	52.5	0.346
BM3	20-May	0	15.3	7.99	9.18	91.7	0.303
	18-Jun	0	22.65	8.59	12.34	143	0.31
	22-Jul	0	27.46	8.93	12.91	163.6	0.302
	19-Aug	0	28.69	9.15	14.95	193.5	0.27
	01-Oct	0	19.74	8.26	9.44	103.4	0.34
BM4	20-May	0	15.62	8.1	8.98	90.3	0.33
	18-Jun	0	22.85	8.43	9.48	110.4	0.341
	22-Jul	0	27.6	8.86	11.48	145.8	0.314
	19-Aug	0	29.1	8.9	14.15	184.5	0.285
	01-Oct	0	20.22	8.12	7.61	84.2	0.342
BM5	20-May	0	11.98	7.71	9.56	88.9	0.506
	18-Jun	0	20.4	8.07	8.28	91.9	0.456
	22-Jul	0	29.66	9.27		Out of Range	0.322
	19-Aug	0	26.04	7.99	6.59	81.4	0.565
	01-Oct	0	16.49	7.99	9.18	94.2	0.589
BM6	20-May	52	10.54	7.47	0	0	0.379
		50	10.63	7.36	0	0	0.378
		45	11.1	7.33	0	0	0.372
		40	11.64	7.32	0.16	1.5	0.365
		35	12.46	7.33	1.19	11.2	0.356
		30	13.02	7.34	1.87	17.8	0.352
		25	14.02	7.36	2.43	23.6	0.347
		20	16	7.53	4	40.6	0.338
		15	16.28	7.73	5.64	57.6	0.336
		10	16.45	8.17	7.81	80	0.334
		5	16.59	8.3	8.41	86.4	0.334
		0	16.84	8.33	8.59	88.7	0.334

Table A-1. (Continued)							
Station	**Date**	**Depth (F)**	**Temp ©**	**pH**	**DO (mg/L)**	**DO (%)**	**Cond (ms/cm)**
BM 6 (Continued)	18-Jun	50	12.16	7.32	0	0	0.367
		45	12.28	7.11	0	0	0.363
		40	12.62	7.1	0	0	0.357
		35	13.08	7.1	0	0	0.354
		30	13.6	7.11	0.34	3.3	0.351
		25	14.37	7.13	0.69	6.7	0.35
		20	16.36	7.15	1.05	10.7	0.354
		15	19.9	7.2	1.77	19.4	0.367
		10	22.3	7.87	6.37	73.3	0.337
		5	22.8	8.26	7.73	89.9	0.335
		0	23.76	8.29	7.71	91.3	0.338
	22-Jul	50	12.92	7.2	0	0	0.389
		45	13.14	7.18	0	0	0.385
		40	13.48	7.22	0	0	0.377
		35	14.22	7.24	0	0	0.377
		30	15.5	7.27	0	0	0.382
		25	18.27	7.29	0	0	0.4
		20	24.02	7.37	0	0	0.396
		15	25.29	7.44	0.66	8	0.372
		10	26.76	7.87	4.31	53.9	0.353
		5	27.92	8.62	8.41	107.5	0.334
		0	28.07	8.67	8.66	110.9	0.334
	19-Aug	45	14.7	7.24	0.35	3.5	0.41
		40	16	7.27	0.01	0.1	0.4
		35	17.17	7.29	0	0	0.399
		30	18.24	7.29	0	0	0.397
		25	21.31	7.28	0	0	0.401
		20	24.69	7.37	0	0	0.373
		15	25.58	7.42	0	0	0.361
		10	27.48	7.67	1.86	23.6	0.329
		5	29.17	8.61	8.1	105.7	0.307
		0	29.82	8.71	10.01	132.2	0.306
	01-Oct	48	19.19	7.29	0	0	0.382
		45	19.25	7.28	0	0	0.38
		40	19.72	7.28	0.1	1.1	0.372
		35	20.13	7.27	0	0	0.364
		30	20.38	7.28	0	0	0.359
		25	20.62	7.29	0.48	5.4	0.355
		20	20.77	7.3	0.63	7	0.35
		15	20.91	7.29	0.59	6.6	0.351
		10	21.16	7.41	1.84	20.8	0.348
		5	21.44	7.66	4.24	48	0.347
		0	22.01	7.68	4.74	54.3	0.347

Table A-1. (Continued)							
Station	**Date**	**Depth (F)**	**Temp ©**	**pH**	**DO (mg/L)**	**DO (%)**	**Cond (ms/cm)**
BM7	20-May	30	13.96	7.51	5.26	51.1	0.311
		25	14.94	7.42	5.05	50.1	0.33
		20	15.46	7.48	5.54	55.5	0.338
		15	15.86	7.69	6.89	69.7	0.341
		10	16.11	8.06	7.86	79.9	0.339
		5	16.2	8.14	8.43	85.9	0.339
		0	16.64	8.18	8.82	90.7	0.34
	18-Jun	30	13.97	7.38	0	0	0.374
		25	14.91	7.21	0	0	0.376
		20	17	7.19	0.35	3.7	0.385
		15	19.5	7.41	4.28	46.7	0.354
		10	22.17	7.78	5.97	68.5	0.35
		5	22.31	8.09	7.14	82.3	0.344
		0	23.48	8.24	7.93	93.4	0.348
	22-Jul	30	16.13	7.48	0.33	3.4	0.422
		25	17.96	7.36	0	0	0.424
		20	22.95	7.36	0	0	0.424
		15	25.53	7.46	2.84	34.7	0.398
		10	27.25	8.29	6.57	82.9	0.332
		5	27.57	8.46	8.04	102.1	0.334
		0	27.76	8.53	8.18	104.2	0.335
	19-Aug	30	19.37	7.24	0	0	0.436
		25	22.36	7.28	0	0	0.418
		20	24.55	7.35	0	0	0.388
		15	26.04	7.46	0.66	8.2	0.354
		10	28.18	8.17	6.45	82.8	0.315
		5	28.58	8.61	8.78	113.5	0.31
		0	29.61	8.78	10.23	134.6	0.309
	01-Oct	29	19.68	7.51	3.88	42.5	0.369
		25	20.51	7.54	3.57	39.7	0.35
		20	20.87	7.56	3.74	41.9	0.345
		15	21	7.59	4.18	46.9	0.344
		10	21.04	7.63	4.56	51.2	0.344
		5	21.11	7.67	4.95	55.7	0.343
		0	21.43	7.74	5.45	61.8	0.345

Table A-1. (Continued)

Station	Date	Depth (F)	Temp ©	pH	DO (mg/L)	DO (%)	Cond (ms/cm)
BM8	20-May	23	13	7.54	7.19	68.3	0.302
		20	15.57	7.84	7.46	74.9	0.324
		15	15.87	7.94	7.72	78.1	0.332
		10	16.02	7.99	7.92	80.3	0.336
		5	16.16	8.06	8.23	83.7	0.333
		0	16.26	8.1	8.4	85.7	0.333
	18-Jun	20	17.12	7.24	0.72	7.5	0.367
		15	19.54	7.42	5.08	55.5	0.355
		10	22.04	7.97	7.36	84.4	0.343
		5	22.39	8.35	8.41	97.1	0.343
		0	22.8	8.44	9.09	105.7	0.344
	22-Jul	20	22.42	7.31	0	0	0.401
		15	25.73	7.41	1.15	14.1	0.353
		10	27.19	7.96	6.3	79.4	0.329
		5	27.62	8.79	10.47	133	0.318
		0	27.77	8.81	10.78	137.4	0.32
	19-Aug	20	24.98	7.3	0	0	0.367
		15	25.9	7.35	0	0	0.356
		10	27.47	7.67	4.78	60.6	0.317
		5	28.59	8.7	10.8	139.6	0.297
		0	28.93	8.82	11.94	155.2	0.296
	01-Oct	17	20.65	7.82	5.78	64.4	0.341
		15	20.7	7.84	5.93	66.2	0.342
		10	20.88	7.89	6.17	69.1	0.34
		5	21	7.91	6.31	70.9	0.341
		0	21.15	7.98	6.81	76.8	0.341
BM9	20-May	32	13.2	7.43	5.38	51.3	0.329
		30	13.34	7.4	5.41	51.8	0.33
		25	14.12	7.38	5.27	51.3	0.339
		20	14.73	7.39	5.42	53.5	0.351
		15	15.67	7.52	6.11	61.5	0.34
		10	15.92	7.86	7.22	73.1	0.345
		5	16.06	8.02	8.13	82.6	0.344
		0	16.33	8.07	8.28	84.6	0.346
	18-Jun	33	13.88	7.45	0.53	5.1	0.381
		30	14.09	7.22	0	0	0.379
		25	15.41	7.19	0	0	0.387
		20	17.46	7.17	0.57	6	0.41
		15	19.6	7.21	1.6	17.4	0.408
		10	21.66	7.47	4.04	46	0.352
		5	22.51	8.04	7.19	83.2	0.354
		0	23.2	8.21	7.76	90.9	0.356

Table A-1. (Continued)							
Station	**Date**	**Depth (F)**	**Temp ©**	**pH**	**DO (mg/L)**	**DO (%)**	**Cond (ms/cm)**
BM 9 (Continued)	22-Jul	33	15.4	7.46	0.63	6.3	0.429
		30	15.81	7.3	0	0	0.427
		25	17.43	7.32	0	0	0.428
		20	21.24	7.34	0	0	0.433
		15	25.63	7.47	1.82	22.3	0.37
		10	27.41	8.5	7.98	101	0.332
		5	27.53	8.64	9.01	114.3	0.33
		0	27.89	8.71	9.38	119.8	0.332
	19-Aug	30	18.17	7.05	0	0	0.454
		25	22.07	7.12	0	0	0.423
		20	24.73	7.29	0	0	0.394
		15	26.09	7.4	0.75	9.3	0.357
		10	27.29	7.6	3.69	46.6	0.331
		5	28.79	8.62	9.9	128.3	0.298
		0	29.72	8.8	11.14	146.8	0.295
	01-Oct	30	18.6	7.5	4.23	45.3	0.423
		25	19.51	7.58	4.57	49.8	0.378
		20	20.67	7.6	4.11	45.9	0.349
		15	20.81	7.56	3.78	42.3	0.347
		10	21.02	7.62	4.43	49.8	0.345
		5	21.11	7.66	4.74	53.4	0.345
		0	21.67	7.69	5.22	59.4	0.345
BM10	20-May	17	12.41	7.48	7.13	66.8	0.33
		15	14.07	7.46	6.9	67.2	0.343
		10	15.01	7.49	6.74	66.9	0.364
		5	15.71	7.58	7.09	71.5	0.373
		0	16.34	7.68	7.55	77.2	0.373
	18-Jun	20	18.33	7.63	5.44	57.9	0.484
		15	19.99	7.62	5.41	59.6	0.433
		10	21.23	7.68	5.6	63.1	0.405
		5	22.12	8.22	8.23	94.5	0.376
		0	22.75	8.4	9.41	109.3	0.378
	22-Jul	22	21.67	7.46	0.9	10.2	0.498
		20	24.25	7.4	0.67	8	0.476
		15	25.41	7.54	4.17	50.9	0.44
		10	27.38	8.26	8.67	109.7	0.307
		5	27.59	8.85	12.6	160	0.297
		0	28.12	9.17	15.14	194	0.294
	19-Aug	20	24.58	7.13	0	0	0.47
		15	26.53	7.23	0	0	0.428
		10	27.43	7.46	3.38	42.8	0.366
		5	28.47	8.59	10.5	135.4	0.292
		0	28.51	8.72	12.1	156.2	0.291

Table A-1. (Continued)							
Station	**Date**	**Depth (F)**	**Temp ©**	**pH**	**DO (mg/L)**	**DO (%)**	**Cond (ms/cm)**
BM 10 (Continued)	01-Oct	20	17.79	7.65	6.49	68.4	0.495
		15	19.89	7.83	6.41	70.4	0.376
		10	20.55	7.89	6.38	71.1	0.348
		5	20.69	7.96	6.54	73	0.347
		0	20.75	7.99	6.94	77.6	0.346
BM11	20-May	0	13.42	7.33	8.24	79.1	0.412
	18-Jun	0	16.65	7.38	8.4	86.4	0.479
	22-Jul	0	28.6	8.38	8.5	109.9	0.263
	19-Aug	0	30.54	8.78	11.53	154.2	0.313
	01-Oct	0	18.92	8.21	10.36	111.6	0.307
BM12	20-May	0	11.67	7.8	8.92	82.2	0.159
	18-Jun	0	20.95	8.58	10.94	122.7	0.206
	22-Jul	0	28.11	8.41	8.02	102.8	0.263
	19-Aug	0	30.81	8.86	11.64	156.3	0.317
	01-Oct	0	19.48	8.51	12.31	134.1	0.306

APPENDIX B

WATER COLUMN CHEMISTRY MONITORING LABORATORY ANALYSIS CERTIFICATES

APPENDIX C

SEDIMENT PRIORITY POLLUTANT AND ARSENIC MONITORING LABORATORY ANALYSIS CERTIFICATES

APPENDIX D

DRINKING WATER MONITORING
LABORATORY ANALYSIS CERTIFICATES

APPENDIX E

SCOPE OF WORK